DECISION ANALYSIS WITH VALUE FOCUSED THINKING AS A METHODOLOGY TO SELECT BUILDINGS FOR DECONSTRUCTION

THESIS

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Abstract

The purpose of this research was to examine the reuse and recycling of building materials on Wright-Patterson Air Force Base. There are a variety of conflicting factors concerning the removal of a building and the model quantitatively evaluates alternatives with respect to the decision maker's values. The research questions were addressed with both a comprehensive literature review as well as the implementation of the value focused thinking methodology. The model found that the temporary living facilities are the alternatives that achieve the highest value. The result of this research effort was a value model that aids decision makers in identifying buildings for deconstruction.

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Chapter 1. Introduction

Introduction

Buildings are identified for removal daily. These buildings may be useless and no longer serve their intended purpose, or a new and more important need for the building site has been identified. Historically, when these structures were identified for removal, they were demolished and the debris was disposed of in a landfill. With increasing awareness of the environment, including a realization of declining natural resources as well as diminishing landfill space, new options are being explored. For example, usable building materials that result from demolition provide an opportunity to be reused new construction or recycled for some other purpose. In fact, large scale implementation of building recovery practices is known as deconstruction.

While deconstruction is an environmentally favorable option, it is not practical for every facility. There may be a number of conflicting factors that hinder or prevent the deconstruction of certain facilities. Examples include: the accessibility of the site (USEPA, 2000), the ease of taking apart the building structure (Macazoma, 2002), the potential to avoid costs (Kartam, 2004; USEPA, 2000), the ability to reduce environmental impact (Chini, 2003; Craighill, 2003; Dantata, 2005; Trankler, 1996) and the increased time and labor requirements (Greer, 2004; Dantata, 2005). The best

disposal option for a given building typically depends on a combination of these factors. However, facility managers may have a difficult time determining which factors are relevant.

Although this dilemma is applicable to both the private and public sector, this research focused on a single Air Force installation: Wright-Patterson Air Force Base (AFB), Ohio. Air Force installations have building demolition programs which are critical parts of the base's comprehensive base development efforts. For example, at Wright-Patterson AFB, a strategic demolition plan outlines the buildings that have been identified for removal, that building's pertinent information, and the reason that the removal must occur. Traditionally, buildings on Wright-Patterson have been demolished and landfilled, but recent projects that incorporated deconstruction processes have been successful. Although environmental managers want to apply deconstruction in place of demolition to more of the base's removal projects, conflicting factors can it difficult to identify the best buildings. Using Wright-Patterson AFB as a case study then, the goal of this research was to demonstrate a methodology that can be used by any facility manager to identify suitable buildings for deconstruction.

Background

Construction and demolition debris is composed of materials such as concrete, wood, asphalt, drywall, metals, bricks, glass, plastics and building components such as plumbing fixtures and carpet (USEPA, 2000). Although a significant amount of this material goes into landfills (Franklin Associates, 1998), there are very few studies that quantify the exact amount of construction and demolition waste that is produced

annually. Reasons for this vary but typically include the fact that C&D debris is often grouped with municipal solid waste data, there are many alternate disposal options (Dolan, 1999), and states have their own definitions of the waste. However, in largest study, Franklin Associates (1998) found that over 136 million tons of building related construction and demolition waste went into landfills in 1996 (this figure does not include the waste from road and bridge removal or renovation) (Franklin Associates, 1998).

Since the early 1980’s, the reuse and recycling of demolition waste has become more common. In fact, the number of processing facilities operating in the Unites States has risen with the most frequently recovered materials being concrete, asphalt, metals and wood. A major reason for this change has been the lack of landfill capacity and the reduction of adequate supply of materials (Trankler, 1996). However, despite increase in recovering these materials, the most common management practice for construction and demolition debris is still landfilling. Only 20-30% of building related construction and demolition debris was recovered in 1996 with 35-35% going into landfills; the remaining waste was managed on site (Franklin Associates, 1998).

Another option for dealing with C&D debris is deconstruction, which is the process of taking apart a building in the opposite order that it was put together to reuse and recycle as much of the material as possible. There are many benefits for choosing deconstruction as a primary waste management system. Instead of mining more metals and cutting down more trees, existing construction and demolition materials can be processed and reused (Greer 2004; Thormark, 2001; Dolan, 1999; Chini, 2003; Poon, 1997; Masood, 2002). Reusing and recycling these components would significantly

reduce the need for natural resources. It would also reduce the strain on declining landfill space and potential hazardous environmental effects that landfill wastes produce (Craighill, 2003; Dantata, 2005; Chini, 2003; Poon, 1997; Trankler, 1996; Wang, 2004). Additionally, in many cases, the net cost deconstruction is comparable to the cost of conventional demolition and landfilling (Chini, 2003; Greer, 2004). The salvaged materials can be sold for recycling application or direct reuse in new building projects. The landfill disposal costs, known as tipping fees, will decrease because a smaller amount of material ultimately enters the landfill.

Despite the advantages to deconstruction, there are certain disadvantages that decrease its desirability. For instance, the increased time, money, and resources required may not be available (Craighill, 2003; Greer, 2004; Dantata, 2005). Another disadvantage is the long-term reduction in the quality of recycled materials. In general, the materials can only be recycled into a product of lesser quality which leads to the term "downcycling." Downcycling does not result in sustainability because the waste must be eventually disposed of. Therefore, reuse rather than recycling is often a more sustainable option (Craighill, 2003; Chini 2003). The final disadvantage is the varying market for salvaged building materials. It is much more difficult to demonstrate the economic desirability of deconstruction if a resale outlet for these materials does not exist (Craighill, 2003; Thormark, 2001; Dolan, 1999).

In addition to the disadvantages of deconstruction, there are many barriers to the practice as a mainstream management technique for building waste. For example, many buildings currently planned for demolition and renovation were not designed for deconstruction, which further increases the required time, money, and resources. The

final barrier is the relatively low cost of landfill disposal. Despite the fact that landfill costs are on the rise, in many areas of the United States costs are still low enough to reduce the appeal of a recycling program (Franklin Associates, 1998).

Traditionally, building demolition has been seen as low technology; the decision maker only wanted fast demolition and rapid clearance of the site. In many cases, reuse and recycling takes place only if the decision maker finds it less expensive than landfilling (Duran, 2006). However, current construction and demolition waste management is more complex and the decision maker often has values other than time and money. Even with the advantages and disadvantages discussed earlier, the best option often varies with each individual project, the local circumstances and the values of the decision maker (Barton, 1996). The final waste management decision should accurately reflect the decision maker's values.

Problem Statement

The purpose of this research was to create a decision model that will help managers determine which buildings are the most appropriate candidates for deconstruction. The questions that must be answered to complete this research are listed below.

1. What materials can be expected in a building structure, what are the basic characteristics of these materials, and what is the reuse or recycling potential of these materials?
2. What are the advantages and disadvantages associated with applying deconstruction operations to a building?

3. What is the basic deconstruction process? What are the additional requirements for deconstruction over traditional demolition and landfilling?
4. When a building must be removed, what values does the decision maker have and how can those values be measured?

Methodology

Existing research on this topic has two basic characteristics. First, in most waste management research, the primary focus has been at the macro level: how nations are developing towards or away from sustainability. However, there also exists a need to develop methods to evaluate sustainability and sustainable development on a smaller scale such as in businesses or projects (Klang, 2003). Establishing targets in a limited system can be a more efficient way to influence behavior and thereby contribute to meeting sustainability goals at the macro level (Klang, 2003). This observation demonstrates an apparent need for analysis on a smaller scale.

The second characteristic is the lack of quantitative studies. While there is a significant amount of published research that addresses recycling of construction and demolition wastes, most studies examine the problem qualitatively. Of the few quantitative studies that were identified, even fewer used multi-objective decision analysis models to examine the differences between recycling and landfilling this waste. Therefore, a need also exists for a multi-objective quantitative approach.

Value Focused Thinking (VFT) is an appropriate methodology to develop a decision model to help assess the deconstruction potential of building because it addresses the research needs stated above. This methodology uses a quantitative

approach to analyze the alternatives; it also examines the reuse and recycling of construction and demolition debris from a small scale perspective. Since there are many factors to consider when planning a building's disposal, the multi-objective nature of the VFT approach was ideal for this research.

Assumption and Limitations

As part of this research, various assumptions had to be made. There are certain parameters associated with measuring a building's deconstruction potential that cannot be accurately predicted. An example is the time to deconstruction a buildings, which is impacted by a variety of factors. Therefore, certain assumptions were necessary to estimate many of the parameters in the model. These assumptions are explained in the appropriate sections of Chapters 3 and 4.

There are certain limitations to this research that must be noted. First even though much of the literature classifies construction and demolition debris as a single type of waste, the model only considered materials resulting from the removal of building structures. Another limitation of this study is accuracy. For many of the parameters in the model, there are not established methods on which to base predictions, since a variety of factors can influence the parameters' values. Therefore, many of the parameters were estimated using published literature and the side of the building in square feet. This many introduce an element of uncertainty to the final results.

A final limitation of the study is the method of determining cost. Projected costs are available for each building from Wright Patterson Air Force Base's strategic demolition plan. This cost represents the expected contract cost for a local contractor to

demolish and remove the building. The decision makers for this analysis are from Wright Patterson's Environmental Management Division. They felt that it would generally be more expensive to require a diversion rate in the contract; therefore, they prefer to encourage the contractor to reuse and recycle the materials by demonstrating that deconstruction can result in overall cost avoidance. They provide the contract with case studies of past successful deconstruction projects, as well as information concerning the costs of reuse and recycling versus landfilling building waste. This limitation will affect the data analysis in Chapter 4.

Significance of Study

The result of this research was a multi-objective decision analysis model that will help determine the best candidates for deconstruction from a group of buildings identified for removal at Wright Patterson AFB. Ultimately, the model enables the decision maker to make more informed decisions based on their objectives for the problem. If limited resources exist, the building with the most deconstruction potential will produce the greatest value. Additionally, this research could be used to help identify deconstruction candidates at other military installations. Although the values of the decision makers at each base may be somewhat different the methodology demonstrated in this research can be applies to provide more insight to those decision makers.

Organization/Purpose of Remaining Chapters

The second chapter of this document contains a thorough literature review that not only summarizes the research already conducted on this topic but also demonstrates the need for a Value Focused Thinking analysis of construction and demolition waste. Chapter 3 contains a summary of the methodology and describes how the Value Focused Thinking approach was applied to build a value hierarchy complete with measures, value functions, and weights. The fourth chapter offers the results and the analysis of this process. Finally, Chapter 5 offers conclusions concerning this research as well as recommendations for future research.

Chapter 2. Literature Review

Introduction

While the reuse and recycling of construction and demolition (C&D) materials has been studied using many different research methodologies, there are very few that apply decision analysis techniques. Most research is either involved either a qualitative or quantitative study examined from a single objective. A decision analysis model that helps identify building deconstruction candidates was not found. Therefore, this chapter will review information about the current state of reusing and recycling C&D materials in the United States. Specifically, the following sections will give information about pertinent regulations and policies, a review of the deconstruction process, information on hazards concerning waste in landfills, information on typical C&D materials and two case studies concerning deconstruction. Additionally, this chapter will briefly discuss the Value Focused Thinking methodology and its application in identifying the buildings most suited for deconstruction.

Regulations and Policies

While there are many federal laws and regulations pertaining to the handling and disposal of waste, federal legislation does not specifically address the handling or disposal of construction and demolition debris. At the federal level, the government groups construction and demolition waste with municipal solid waste. Therefore, jurisdiction over this waste falls under the Resource Conservation and Recovery Act (RCRA) (Clark, 2006). The purpose of RCRA is to protect the environment and human

health from waste hazards, conserve resources, and promote environmentally safe waste handling. RCRA requires that the waste be characterized as hazardous (regulated under Subtitle C) or non-hazardous (Regulated under Subtitle D) (Resource Conservation and Recovery Act, 1976). Although construction and demolition waste is generally classified as non-hazardous (Franklin Associates, 1998), certain materials could fall under Subtitle C regulation. The most common of these hazardous materials are asbestos, poly chlorinate biphenyls (PCBs), and lead-based paint. Hazardous materials are discussed in more detail later in this chapter.

In addition to RCRA, the Pollution Prevention Act applies indirectly to the reuse and recycling of C&D waste. This act focuses on reducing pollution by changing production, operation, and raw materials use. Compliance with this legislation involves promoting efficient use of energy, water, and natural resources. The reuse and recycling of C&D materials promotes the efficient use of natural resources and aids compliance with this law (Pollution Prevention Act, 1990)

The Occupational Safety and Health Act (OSHA) also pertains to C&D waste reuse and recycling. Intended to provide a working environment free from known safety and health hazards, OSHA addresses not only generic safety issues on a construction site but also the danger of working in close proximity to hazardous materials. This law is relevant because there may be additional training and notification requirements necessary for personnel before starting a deconstruction or demolition project (Occupational Safety and Health Act: Strategic Plan, 2006).

In addition to legislation, various Executive Orders have been passed with the intention of reducing the federal government's impact on the environment. The most

recent is Executive Order (E.O.) 13423, which was signed in January 2007. This order mandates that Federal agencies will conduct activities in fulfillment of their missions in an environmentally sustainable and cost-effective manner. This order specifically mandates the use of sustainable environmental practices as well as increasing the diversion of solid waste. Additionally, this order addresses incorporating sustainable principles into construction and renovation of buildings. The implementation plan associated with this order requires that each agency will establish and submit their solid waste reduction goals by April 2007. E.O. 13423 demonstrates the president's interest in addressing environmental impact, and further shows that the federal government recognizes the need for policies to promote environmentally friendly practices.

While C&D debris is considered municipal solid waste at the federal level, state and local regulations vary from state to state. Each state typically has an individual definition for construction and demolition debris (Clark, 2006). Many states make no specific provisions for C&D debris, while others have very specific rules regarding its disposal (Franklin Associates, 1998). Regulations for groundwater monitoring, liner construction, site restrictions, financial assurance, training, and regulations for recycling vary (Clark, 2006). This makes tracking the exact amount of C&D debris difficult.

The Department of Defense (DoD) and the United States Air Force have regulations concerning solid waste management. The DoD Directive 4165.60 seeks to conserve natural resources by collecting and disposing of solid waste in a careful manner, reducing the amount of wasted material, and diverting materials from environmentally unfriendly disposal methods (Dolan, 1999). Additionally, each Air Force installation must have a solid waste management program to comply with federal, state, and local

waste regulations as well as any applicable Air Force Instructions (Air Combat Command, 1994). In 1998, the DoD issued a measure of merit seeking a 40% diversion rate of solid waste before 2005. When diverting this waste, bases were to ensure that waste management programs provided an economic benefit when compare with landfill disposal, or other disposal methods (Goodman, 1998). The deadline for meeting this rate has already passed, but a new diversion goal has not been set. Many Air Force bases already meet this rate, but finding ways to divert large volumes of waste will not only aid in continuing to meet this goal but also prepare an installation for any future increases in the required diversion rate.

Deconstruction Process

Deconstruction is the process of selectively dismantling a building and removing materials for reuse or recycling from the buildings prior to and during the removal process (Franklin Associates, 1998). While the exact process for deconstruction of buildings is not universally established (Chung, 2003; Kartam, 2004; Poon, 1997; Fatta, 2003), the following basic steps comprise a typical deconstruction process (Chini, 2003; Poon, 1997):

1. Remove the trim work, including door casing and moldings;
2. Take out kitchen appliances, plumbing, cabinets, windows, and doors;
3. Remove the floor coverings, wall coverings, insulation, wiring, and plumbing pipes;
4. Disassemble the roof; and
5. Dismantle the walls, frame, and flooring, one story at a time.

There are two types of building deconstruction: non-structural and structural. Non-structural deconstruction refers to the removal of non-load bearing components of a building such as windows, doors, appliances, sanitary ware, cabinets, electrical fixtures, etc. Structural deconstruction refers to dismantling the actual components of the building structure such as the frame, roof, and walls (Macozoma, 2002). For the remainder of this document, the term deconstruction will refer to both non-structural and structural deconstruction.

Planning for Deconstruction

Before building deconstruction or disassembly takes place, certain factors should exist to ensure success. First, the condition of the building must be examined. Not every building is suitable for deconstruction; it may not possess components of value or it may not be in the right physical condition to be disassembled (Chini, 2003; Dantata, 2005). Therefore, determining that the building is a good candidate for deconstruction is imperative. Additionally, the age and type of facility should be noted; these factors are indicators of the quality and type of materials that can be expected from the structure. The accessibility and location of the site should also be examined. An open site can dramatically decrease labor costs, while limited site access can increase the cost (USEPA, 2000) and possibly make demolition a more desirable option.

One must also ensure that adequate time, money, and resources are available (Chini, 2003). Deconstruction is more time consuming than traditional demolition and landfilling because components are removed and sorted by hand. This increase in time typically requires the hiring more workers (USEPA, 2000). In many cases, additional training in deconstruction and correct handling of materials is also necessary (Fatta,

2003). Availability of these resources should be assessed before deconstruction is chosen.

One should also examine the simplicity of the process which is determined primarily by two elements. The first is its design for deconstruction. Design for deconstruction refers to the intention in the original building design for efficient end-of-life disposal. The second element is the feasibility of deconstruction refers to the assessment of the building composition and conditions as well as the determination of the likelihood of success. If these two elements can be proven to exist, then deconstruction operations will likely be successful (Macazoma, 2002).

Other important considerations before beginning a deconstruction project are the federal, state, and local regulations. These requirements will vary among states and counties. Contractors should ensure that all the necessary environmental assessments and permits have been obtained. Additionally, hazardous materials must be considered (Chini, 2003). If found, they must be disposed of in an appropriate manner and usually at an increased cost when compared to inert materials. Hazardous materials are discussed in more detail later in this chapter.

Examination of the processes and resources available is also important before beginning a deconstruction project. Organized collection and transportation means for materials must be available to the deconstruction site. A facility that accepts C&D materials for reuse and recycling should be relatively close to the site (Thormark, 2001). If such a facility does not exist within reasonable proximity to the site, there will probably be no outlets for resale (Dolan, 1999). Additionally, careful sorting either at the site or at a treatment center must be possible. Also, some means to reprocess the

materials is generally necessary before they can be sold or recycled (Kartam, 2004). The existence of these processes and resources makes deconstruction a more desirable waste management option.

In deconstruction planning, it is also important to ensure that a market for reused or recycled materials exists. The markets have three equally important elements: C&D waste materials supply, secondary material industries, and end markets for products (Macozoma, 2002). A shortage of raw materials within the local area makes a reliable supply of suitable reused or recycled materials more desirable, especially if those materials are very competitive with virgin materials in terms of cost and structural reliability (Kartam, 2004; USEPA, 2000). Reused and recycled, or secondary material industries refer to the ability to reprocess and finish the salvaged materials. The end market refers to the customers who are interested in buying secondary building materials. The amount and type of C&D materials available in any given region will depend on the economic conditions, weather, major disasters, special projects, and local regulations (Franklin Associates, 1998).

Advantages, Disadvantages and Barriers

Much of the published research concerning C&D debris and deconstruction examines the potential advantages and disadvantages of reusing and recycling material instead of landfilling it. It is important to recognize these factors in order to choose the most advantageous disposal method for a given demolition project. Not only will these factors help to focus the values of the decision maker during the Value Focused Thinking process, they will also aid in evaluating alternatives. In addition to offering advantages

and disadvantages, many authors discuss barriers in addition to the disadvantages that may explain why reuse and recycling C&D waste has not become more common.

Advantages

There are a variety of advantages associated with deconstructing buildings compared to traditional demolition and landfilling. These advantages are important to understand when analyzing buildings for their deconstruction potential. The advantages identified in this research are a reduced strain on raw materials, diversion of waste from landfills and the potential for cost avoidance.

When reusing and recycling construction and demolition waste, materials are reused and fewer natural resources have to be collected, processed, and transported (Thormark, 2001; Dolan, 1999). For example, metals reuse and recycling significantly alleviates the pressure natural mineral resources (Craighill, 2003; Greer, 2004; Chini, 2003; Poon, 1997; Masood, 2002). Therefore, reuse and recycling promotes sustainability by, which can be further promoted if the salvaged building materials are used in new construction. In addition to decreasing extraction of new materials, reducing the processing of raw materials means less energy consumption overall. This decreases the pollution associated with manufacturing (Chini, 2003; Craighill, 2003).

Besides alleviating the pressure on natural resources, a reuse and recycling program has the potential to divert millions of tons of C&D waste from landfills (Craighill, 2003). The United States has a finite amount of land and cannot continue to build and demolish structures without considering the limitations on landfill space. C&D waste has a large volume so diverting these large and bulky materials will increase the lifetime of the landfill (Dolan, 1999). Deconstruction practices can achieve diversion

rates as high as 90%. Thereby, keeping a large portion of this high-volume waste out of landfills and help reduce the strain on the life of landfills (Dantata, 2005; Chini, 2003; Poon, 1997; Trankler, 1996; Wang, 2004). Besides decreasing the pressure on declining landfill space, diverting waste also decreases the negative environmental and health effects associated with a high volume of landfill waste.

In addition to diverting waste from landfill sites, there are potential economic benefits involved with a recovery program. Recovering C&D components is economically favorable if the overall cost of the deconstruction project is less than the cost of demolition and landfilling. Although labor costs are typically higher than conventional disposal, the tipping fees saved by diverting materials are significant (Chini, 2003), since demolition for one building site can result in thousands of tons of waste (Greer, 2004). In addition to avoiding the tipping fees for the diverted materials can be reused, recycled or resold to a processing facility or directly to another organization (Chini, 2003). Certain qualities and characteristics of salvaged materials make them more desirable for resale. Heavy timbers and unique woods from wood-framed buildings such as Douglas fir, American chestnut, and old growth southern yellow pine have high resale values. These components are often found in buildings that were constructed before World War II. High value specialty items such as hardwood flooring, architectural moldings and unique doors or electrical fixtures can be very valuable (Chini, 2003). Finally, tax benefits for individuals or groups that choose to reuse and recycle demolition materials can offset the initial increase in deconstruction costs (Greer, 2004).

Disadvantages

With the advantages, there are certain disadvantages of reusing and recycling C&D materials. These disadvantages are partially responsible for the fact that deconstruction practices are not more widely used. The disadvantages identified in this analysis are the need for increased resources, downcycling, and the varying market for reused and recycled materials.

Because of the nature of the deconstruction process, additional time and money will be needed to remove the building structure from the site. The initial cost of deconstruction (without factoring in the resale value of the materials salvaged) will likely be higher than traditional demolition. Because recycling is inherently more time consuming that traditional demolition, there are increased time requirements (Chini, 2003; Greer, 2004; Franklin Associates, 1998). In the construction and demolition industry, time is critical (Klang, 2003) and any factors that increase a project's time are generally not preferred. There are also increased costs associated with transport, reprocessing, labor, storage, sorting, planning and specialized machinery (Craighill, 2003; Greer, 2004; Dantata, 2005).

In addition to the potential for increased cost, the concept of downcycling is a common disadvantage to recycling. When a material is recycled and reprocessed, it is often for a lower grade purpose (Craighill, 2003; Chini, 2003). In other words, downcycling is not a sustainable process because as the material is reprocessed, its value and quality will continually decrease until it is useless and must be disposed of. Reuse, which does not require extensive reprocessing of the materials, is generally a preferred waste management option.

Another disadvantage of salvaging C&D materials is the variance in the markets for reused and recycled building materials. Reclaimed materials are generally not trusted and the quality of reused and recycled products is still not definite (Craighill, 2003; Thormark, 2001; Dolan, 1999). There are also restrictions on the use of some materials; for instance, salvaged lumber cannot be used in all structural applications (Greer, 2004; Kartam, 2004). Virgin raw materials can be relatively cheap, which discourages the purchase of reused materials that may be structurally unreliable (Poon, 1997). Additionally, the availability of vendors for reused and recycled materials is limited. Not all sites will have access to a facility that accepts these materials.

Barriers

The research indicates that certain barriers exist which have made large-scale recovery operations for C&D materials more difficult. One major barrier is in the design of the structure. Architects of the past never intended for their buildings to require disposal and designed buildings to stand forever. The design of these older structures makes removing building components much more difficult (Chini, 2003; Crowther, 2001).

The complicated economics of reusing and recycling these materials is another barrier. It is more expensive to collect and process the materials than to landfill them (Franklin Associates, 1998). The money, time, and labor that the process takes make the deconstruction of many buildings economically unattractive (Craighill, 2003; Chini, 2003). Additionally, the cost of primary materials is relatively low and, in many areas of the United States, the landfill disposal cost is also low. Therefore, reusing, recycling, or buying these building materials may not be economically desirable (Craighill, 2003;

Poon, 1997; Kartam, 2004). Many also question the quality of reused and reprocessed materials, and there is very limited testing done to prove that these materials are suitable for reuse (Thormark, 2004). Therefore, many builders would rather use more expensive primary materials than risk using recycled materials that they perceive to be less reliable (Franklin Associates, 1998). In order for the recycled materials to be marketed as a substitute for new raw materials, they must satisfy certain technical specifications and be economically competitive (Kartam, 1051).

Finally, the lack of an existing recovery procedure prevents many decision makers from choosing to salvage materials (Dolan, 1999). There is neither an existing method nor framework for the process and nor “a broad industry identity with commensurate standardized practices” (Chini, 2003). Thus, many decision makers are reluctant to take on a deconstruction project because they lack the specialized knowledge or experience needed.

Landfilling C&D Waste

C&D waste is typically placed in landfills separate from municipal solid waste. Because much of this waste stream is considered inert, legislation in many states does not require C&D waste landfills to provide the same level of environmental protection as a municipal solid waste landfill (Clark, 2006). The primary differences between the two types of landfills are the liner and leachate collection systems. Because C&D waste is mostly non-hazardous, regulations for the groundwater protection systems are not as stringent (Franklin Associates, 1998).

As with all landfills, there are chemical and biological threats that may create hazards both to human health and the environment. The methane-rich gas that landfills release is highly flammable and makes fires and explosions possible (El-Fadel, 1997). Landfill emissions also include methane, carbon dioxide, and trace concentrations of a wide variety of other gases (Parakaki, 2005). These landfill emissions contribute to global warming and can also cause vegetation damage in addition to releasing unpleasant odors (El-Fadel, 1997; Parakaki, 2005). Despite being generally inert, more recent studies show that building components have the potential to impact the quality of the groundwater (Clark, 2006; Weber, 2002). Leachate from the landfill is the most significant threat and has been associated with the contamination of the underlying aquifers (El-Fadel; 1997). From these landfill hazards, the environmental issues with construction and demolition wastes are evident. These factors further indicate the necessity for increased reuse and recycling operations in order to divert waste from these sites.

Typical C&D Waste Composition

Building composition will always be varied. It will depend on the type of construction and the methods used by the local construction industry (Franklin Associates, 1998). It will also vary depending on the mission of the facility, the age of the structures, climate (Franklin Associates, 1998), and building styles (Wang, 2004; Moulton-Patterson, 2002). The following sections discuss the characteristics of specific waste materials and examine their potential for reuse and recycling. Deconstruction materials considered hazardous must be properly disposed of; however, these materials

are not discussed. The most frequently cited of the materials are asbestos based insulation, polychlorinated biphenyls and lead based paint (Fatta, 2003)

Metals

In buildings, metals can generally be found in plumbing and heating components, some roofing materials, and electronic devices (National Mining Association). They can also be found in structural applications, windows, doors fasteners and other uses. For most building type though, metals will only be a small proportion of the total composition, generally between one and three percent (Sandler, 2003). Until the last two centuries, metals were too scarce and valuable to discard, but recent rates of extraction have been so fast that metals waste has been on the rise (Ayers, 1997). Because of the intensive processing requirements fore primary metals as well as the recognition that a reliable supply of processed metals already exists within these building structures, metals reuse is on the rise (Ayers, 1997).

Metals are one of the most commonly recycled building materials (Ayers, 1997; Kartam, 2004; Franklin Associates, 1998). For example, steel is highly recyclable and according to the Steel Recycling Institute, up to 85% of it is recycled. This is due to its many uses and forms, magnetic properties and high value (Kartam, 2004; Yost, 1998). Furthermore, aluminum and ferrous metals like copper and brass have generally been recovered because good markets for resale have existed for years (Kartam, 2004; Moulton-Patterson, 2002; Franklin Associates, 1998). Structural elements and studs made from metal are also suitable for reuse (Thormark, 2001).

Gypsum

Gypsum is the main component of wallboard, and is also known as drywall and sheetrock. It has been used extensively in the United States for the construction of interior walls and ceilings since 1950 (Sandler, 2003). It is estimated that 30 million tons of drywall are made each year in North America (Unknown, 1992). The basic drywall panel consists of a gypsum core sheet surrounded by a paper wrapper. Gypsum can account for 5-25% of a building's composition, but the average is about 12% (Sandler, 2003; Moulton-Patterson, 2002).

Gypsum panels can often be reused for production of new board (Manuel, 2003; Moulton-Patterson, 2002; Yost, 1998; Dolan, 1999). Even the paper backing can be separated and recycled into new paper backing (Franklin Associates, 1998). Ground gypsum and wallboard can be used as a litter bed for chicken and turkey houses (Thormark, 2001; Yost, 1998). In some studies, certain types of drywall were used as an additive to soil and were found to increase corn yields and soil fertility (Moulton-Patterson, 2002; Yost, 1998). The benefit to recycling gypsum into new drywall is the decreased use of new gypsum stone and decreased transport of raw gypsum stone from quarries to factories (Thormark, 2001).

Concrete

Concrete is made up of cement, water, and aggregate such as crushed stone, sand. or grit (Franklin Associates, 1998). In building structures, concrete can be found in the foundation, the walls, floors, and roofs (Dolan, 1999); the amount of concrete can be anywhere between 0 to 50%. The exact percentage varies depending on the type of facility (Moulton-Patterson, 2002; Sandler, 2003).

In principle, all masonry and concrete can be recycled or reused (Kartam, 2004). Concrete is not easily used in the form that it is salvaged, but it can be crushed and used as new aggregate (Dolan, 1999). Recycled concrete is mostly used in replacements for road-based gravel as a base or sub-base, but it is also used as an aggregate in asphalt or concrete (Franklin Associates, 1998; Thormark, 2001; Moulton-Patterson, 2002). To be recycled, concrete must be crushed and any metals or other materials must be removed. In the past, concrete was a single- use material because time loading affected its physical features (Kartam, 2004). For this reason, recycled concrete is often used as lower standard aggregates and for non structural, non-load bearing applications (Kartam, 2004). Recycled concrete is produced by partially replacing cement with crushed concrete particles (Masood, 2002).

Wood

The majority of structures in the United States are wood-framed buildings (Sandler, 2003). Hand demolition rather than the use of heavy machinery will yield more lumber that can be salvaged for reuse. Untreated wood is ideal for reuse; however, in many cases wood is often painted or waterproofed. Therefore, these materials must be handled as contaminated waste due to the chemical content and the risk of pollution to the groundwater (Kartam, 2004). Wood can comprise up to 80% of the total building composition in wood-framed residential buildings and as little as 20% in other types of structures (Moulton-Patterson, 2002; Sandler, 2003).

Wood and timber can often be used in construction or in agriculture unless it has been treated or painted (Craighill, 2003); therefore, all wood is not necessarily suitable for reuse or recycling (Franklin Associates, 1998). However, new tools such as

pneumatic de-nailers and machines to strip lead-based paint make it easier to recover usable wood products (Manuel, 2003). Once recovered, reuse in new construction is the preferred waste management option for wood as long as it has been inspected and meets certain standards (Moulton-Patterson, 2002). In addition to reuse in construction, there are many uses for recycled wood: erosion control and groundcover, organic soil amendment, shipboard export as fuel wood, animal bedding, fertilizer amendment, and incineration. Uncontaminated wood can also be shredded and used for gardening and farming (Kartam, 2004), as well as for fuel in biomass facilities (Thormark, 2001). Additionally, recycled wood can be used in engineered woods such as particle board, masonite, laminated wood, and plywood (Moulton-Patterson, 2002).

Asphalt

Asphalt can be found in pavements for roads, bridges, parking lots, roofing, and resilient flooring. Asphalt shingles are commonly used on slanted roofs of residential buildings and comprise about two-thirds of the residential roofing market (Franklin Associates, 1998). On average, these shingles account for 8% of the total building composition (Sandler, 2003). To be recycled, these shingles are generally removed by hand (Dolan, 1999). The common recycling uses for these shingles include hot and mix asphalt paving for repairing potholes in roads (Moulton-Patterson, 2002) and new roofing materials (Franklin Associates, 1998). However, meeting the specifications for paving and roofing materials is limiting the growth of suitable recycling processes (Franklin Associates, 1998).

Bricks

Bricks are commonly found in the wall materials of buildings and sometimes as paving materials. The potential to reuse bricks is quite high. Certain types of mortar are very easy to separate and resale markets for bricks are well established. Each brick must be separated and cleaned before it can be resold. If direct reuse is not feasible, bricks can also be crushed as aggregate and used for applications similar to concrete (Dolan, 1999).

Building Fixtures

Doors, windows, cabinets, carpets, furniture, chalkboards, ceiling lights, etc., can generally be removed and reused. Most components, such as windows, doors, and cabinets, can be removed and resold (Manuel, 2003; USEPA, 2000). Older or unique buildings may have valuable wooden fixtures, moldings, casings, sashes, and framing. These components will have a high resale value and are generally salvageable (Moulton-Patterson, 2002; Dolan, 1999).

Case Studies

University of Florida

The University of Florida's Center for Construction and Environment deconstructed six houses during 1999 and 2000 to examine the difference in costs of deconstruction and traditional demolition. The houses varied in size and age and each had a unique material composition. Time and costs for the deconstruction of each building were well documented. The results from this project demonstrate certain guidelines that can be applied to other deconstruction projects. First, deconstruction can be an economically competitive waste management option to traditional demolition.

Second, wood framed structures are the easiest to deconstruct. Finally, the need to store a large volume of material for long periods of time posed a problem with available space (Guy, 2000)

Presidio of San Francisco: Building 901

The deconstruction of Building 901 generated an 87% recovery rate of materials by volume. This case study demonstrates certain conclusions about deconstruction that can be applied to other projects. First, after considering the resale value of the salvaged material and the avoided tipping fees, deconstruction can be a cost-effective alternative to traditional demolition and landfilling. If a crew has experience with deconstruction, the final recovery rate can be increased. Additionally, because deconstruction takes more time than demolition, the amount of time available for the removal of the building must be considered. Finally, the need for additional storage may be necessary if a high percentage of materials is expected to be salvaged.

Value Focused Thinking

The methodology for this research is a decision analysis technique called value focused thinking (VFT). Traditional decision making concentrates on the alternatives and their potential outcomes. However, the VFT process focuses on the values of the decision maker rather than the alternatives that are available; alternatives are only means to achieve objectives (Keeney, 1996). . Values are the fundamental objectives that the decision seeks to achieve, so they should be the focus of analysis (Keeney, 1992). This is considered a proactive rather than reactive method of examining of the problem (Keeney,

1996). The following sections give more information on the process, the advantages and the applicability to identifying deconstruction candidates.

The process used in this research was the ten step process shown in Figure 2.1. In the first step, the fundamental problem is identified. This helps to focus the analysis on exactly what the decision maker is trying to achieve. The value hierarchy is created in step two. All of the decision maker's values are identified and then organized into a hierarchy. The most important values should be in the first tier; these values are further decomposed into various tiers of sub-values. Value hierarchies should be complete, non-redundant, decomposable, operable and relatively small (Kirkwood, 1997). In the third step, the means to measure the lowest tier values are determined. The focus of this step is determining the methods and scales for the. In Step 4, the decision maker creates value functions for each measure. The *y*-axis will have a range of zero to one, and the *x*-axis will be the potential range of each measure. This step not only normalizes the measures, but also encourages the decision maker to realistically think about the measures and determine what quantities are desirable. In the fifth step, the decision maker determines weights for each value and measure in the hierarchy. In this step, they are identifying how important a value is relative to the other values in the hierarchy. In Step 6, alternatives are generated. For this problem, creative alternative generation is not necessary because the alternatives are already established. Step 7 is the scoring of the alternatives by evaluating each alternative against the measures.

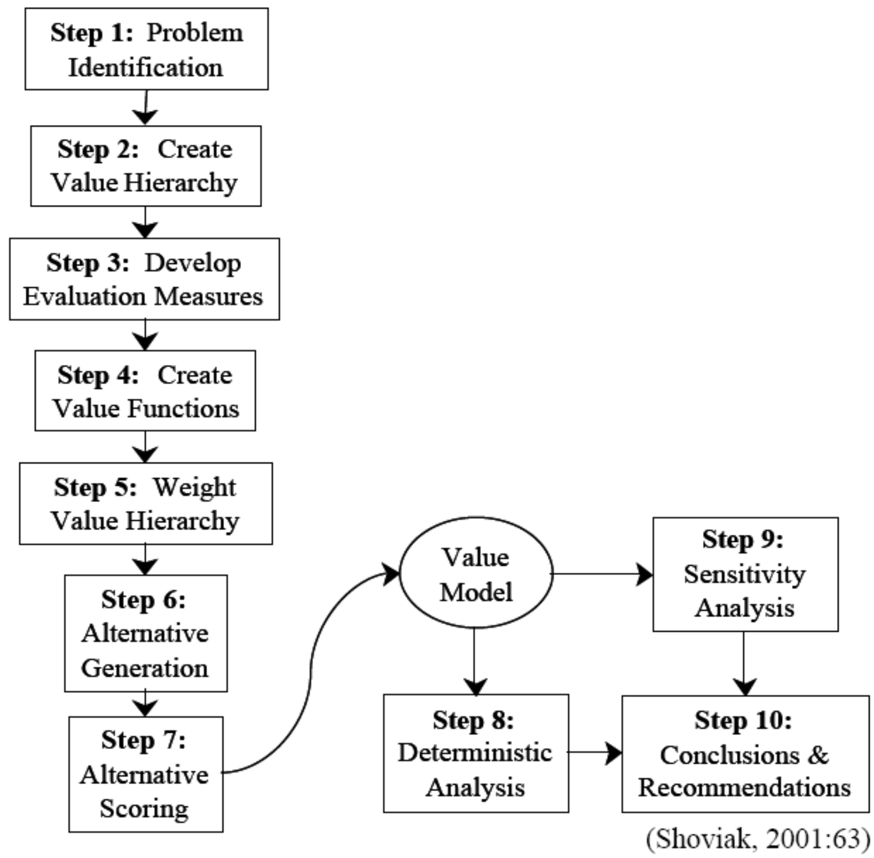


Figure 2.1. Value Focused Thinking Process

After creation of the hierarchy and scoring of alternatives, analysis can begin. In Step 8, deterministic analysis is performed for each alternative by adding the weighted value of the measure score to produce an overall score. The alternatives with higher values are preferred over those with lower values. In Step 9, a sensitivity analysis is performed to determine how sensitive the alternatives are to changes in the weights of the hierarchy. For each value and measure, the weight is varied to see how the ranking of

alternatives changes. Finally in Step 10, recommendations for the most preferred alternatives are made (Keeney, 1992). The result of this process is identification of alternatives that reflect and fulfill the decision maker's values.

Advantages

Value focused thinking helps to create better alternatives for decision problems (Kirkwood 1997; Kenney, 1996). Alternative focused thinking is a reactive approach. A decision problem arises and alternatives are generated to solve that problem which results in a limited pool of alternatives (Keeney, 1996). Conversely, for VFT, the fundamental values of the decision maker are identified first, so actions can be taken to achieve those values. In Step 6, of the ten step process, alternatives are generated based on the value hierarchy. The result is a pool of more creative alternatives that better reflect the decision maker's values.

Value focused thinking helps to develop an enduring set of guiding principles for an organization (Keeney, 1996). Whether there is a decision opportunity or not, it is useful for an organization to list and organize their fundamental objectives. For many, simply listing their values allows for more focused actions to achieve those values (Kirkwood 1997).

Value focused thinking is considered an appropriate methodology for analyzing deconstruction candidates. The existing literature concerning the reuse and recycling of C&D debris lacks qualitative, multi-objective research. The factors that influence a building's removal are varied and dependent upon a variety of factors. By focusing on the decision maker's values, more effective choices can be made concerning a building's final removal.

Chapter 3. Methodology

Introduction

The steps for the value focused thinking process were described in Chapter 2. This chapter will further explore the first six steps and apply the process to the deconstruction of buildings at Wright Patterson Air Force Base. The following sections provide discussion on the problem identification, creation of the value hierarchy, determination of the evaluation measures, creation of the value functions, determination of the weights, and finally the generation and scoring of alternatives.

Step 1: Problem Identification

The first step in the value focused thinking process is defining the problem. Here, the decision maker states and explains the problem the decision analysis model is intended to solve. This step is important because accurately identifying and defining the problem is necessary so that when the model is created, it addresses the intended problem and provides insight that is useful.

This research examined the reuse and recycling of demolition materials. Department of Defense and Air Force buildings are regularly identified for removal. Deconstruction is a removal option that promotes environmental sustainability and can be a very competitive alternative to traditional demolition under certain conditions, which are complex and vary for each building. The literature review demonstrated potential benefits associated with deconstructing these structures as well as the conflicting disadvantages that influence the removal decision. At Wright Patterson Air Force Base, a

number of buildings have been identified for removal before 2011. While the desire to divert landfill waste by deconstruction exists, it is difficult to determine which of the identified buildings will be the best deconstruction options. Therefore, the fundamental objective for this model was to identify the best deconstruction candidates with respect to the decision maker's values.

Step 2: Create Value Hierarchy

The next step in the value focused thinking process is creating the value hierarchy. A value hierarchy is a method of organizing and structuring the values of the decision maker.

To identify these values and their relationships to each other, a variety of techniques are available (Keeney, 1996). Jurk (2002) captured these techniques in the table shown as Table 3.1 which demonstrates the methods that can be used to generate the values of the decision maker.

Table 3.1. Techniques for Identifying Decision Maker Values

Technique	Questions
Develop a wish list	What do you want? What do you value? What should you want?
Identify alternatives	What is a perfect alternative, a terrible alternative, and a reasonable alternative? What is good or bad about each?
Consider problems and shortcomings	What is wrong or right with your organization? What needs fixing?
Predict consequences	What has occurred that was good bad? What might occur that you care about?
Identify goals, constraints and guidelines	What are your aspirations? What limitations are placed on you?
Consider different perspectives	What would your competitor or constituency be concerned about? At some time in the future, what would concern you?
Determine strategic values	What are your ultimate values? What are you values that are absolutely fundamental?
Determine generic values	What values do you have for customers, your employees, your shareholders, yourself? What environmental, social, economic or health and safety objectives are important?

(Jurk, 2002)

The next step is to organize these factors into a hierarchy. The top value is the fundamental objective of the analysis. In this case, the fundamental objective was to find the best candidates for deconstruction from a group of buildings that have been identified for removal. Below the fundamental objective are the first-tier values. These should be

general values that decompose the fundamental objective into more specific areas. The first-tier values should then be decomposed into more specific areas to make the second-tier values and so on until all of the decision maker's values are reflected in the hierarchy.

There are five desirable characteristics that a value hierarchy should achieve in order for the subsequent analysis to be accurate. First, the hierarchy should be collectively exhaustive or complete. This means that all of the decision maker's values concerning the decision should be reflected in the hierarchy. A complete hierarchy increases the accuracy of the model because all of the factors that are important to the decision maker are included in the analysis. Completeness also refers to the degree that measures reflect the attainment of the associated objectives. Essentially this means that the measures accurately evaluate the values that they are intended to measure (Kirkwood, 1997).

Second, the hierarchy should demonstrate non-redundancy, which is also known as mutual exclusivity. This concept states that no values should be repeated anywhere else within the hierarchy. If a value is repeated in the hierarchy, or another value contains a significant amount of overlap, then the importance of this value will be overestimated in the overall value function. Ensuring mutual exclusivity of the hierarchy avoids counting values twice within the overall value function (Kirkwood 1997).

Third, value hierarchies should be independent, which is also referred to as decomposability. This means that a decision maker's preference concerning one value should not affect their preference regarding any other values in the hierarchy. For example, consider an individual who is trying to choose a job and values both salary and benefits. If the benefits for one job are exceptional, then this person may not care as

much about having a high salary. Here, doing very well in one measure influences how the decision maker feels about other values. The value hierarchy should be constructed so that this influence does not occur (Kirkwood, 1997).

Fourth, the hierarchy should be operable. The value hierarchy should be constructed with practicality in mind and individuals who are not necessarily experts on the topic of interest should be able to easily understand and use it. Ensuring that a hierarchy is subjective involve a compromise to ensure that each of the model's intended users can understand it. A hierarchy that is not operable is a less useful tool for analyzing decisions (Kirkwood, 1997).

Fifth, the hierarchy should have relatively small size. A smaller hierarchy is preferred because it is much more easily communicated. This assists the operability of the hierarchy and aids in keeping the analysis simple. Additionally, evaluating the alternatives against a smaller value hierarchy requires less time and research than for a larger hierarchy. There is a tendency to continue to add values to a hierarchy with the intent to ensure that all of the decision maker's objectives are adequately represented. Unfortunately, this can result in a hierarchy that is so large and complex that evaluating alternatives with respect to decision maker values will be very difficult (Kirkwood, 1997).

In creating the hierarchy for this research, the first step was a brainstorming session with the decision makers guided by the questions in Table 3.1. The decision makers were first asked to list all of the factors they felt were important when considering a building's disposal. They were then asked to decompose these factors into more specific values. The decision makers were also asked to describe the characteristics of

their ideal building deconstruction candidate. They were then asked about the positive and negative factors they encountered throughout their experience with deconstruction projects. Finally, the decision makers were asked about the constraints that make deconstruction a less desirable option. The result of this discussion was a list of factors that represented their values.

Rather than using a formal concept mapping approach, these factors were organized into a value hierarchy largely through discussions which examined the relationships and similarities among the factors that were listed. Additionally, any factors that overlapped were either redefined or refocused for independence purposes. The decision makers were asked why they listed a given factor as one of their values and asked to identify the ultimate objective the value was trying to achieve. The factors were organized into four groups which the decision makers agreed were their basic objectives for building removal projects. These four objectives became the first-tier values in the hierarchy. Mission Impact, Potential for Cost Avoidance, Simplicity, and Environmental Impact. Figure 3.1 shows the first tier of the value hierarchy.

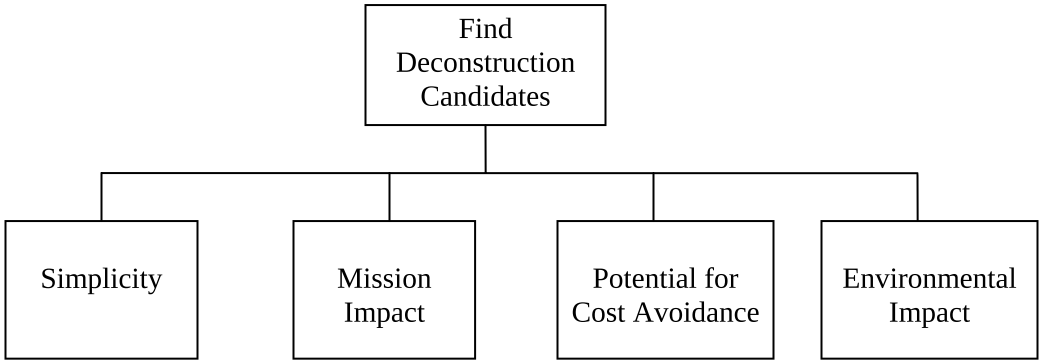


Figure 3.1. First-Tier Values

Simplicity of the deconstruction process is an important consideration when determining the best deconstruction candidates. If it can be shown that the process is relatively simple, then deconstruction is a much more desirable option. The simplicity of the process is heavily influenced by the site characteristics. First, the decision makers favored an accessible building site. From their experience, the decision makers knew that workers should have relatively easy access to the site, which is a factor that may pose a problem for a building site on a military installation. Additionally, the decision makers stated that the space surrounding the building site should be available for the storage of salvaged materials. The site's location is also important. The decision makers felt that a building site that is far away from a landfill but close to a facility that accepts salvaged building materials would have an ideal location. Besides the site, the characteristics of the building also influence the simplicity of the deconstruction process. The decision makers stated that some buildings would be easier to physically dismantle. Figure 3.2 shows the simplicity branch from the hierarchy.

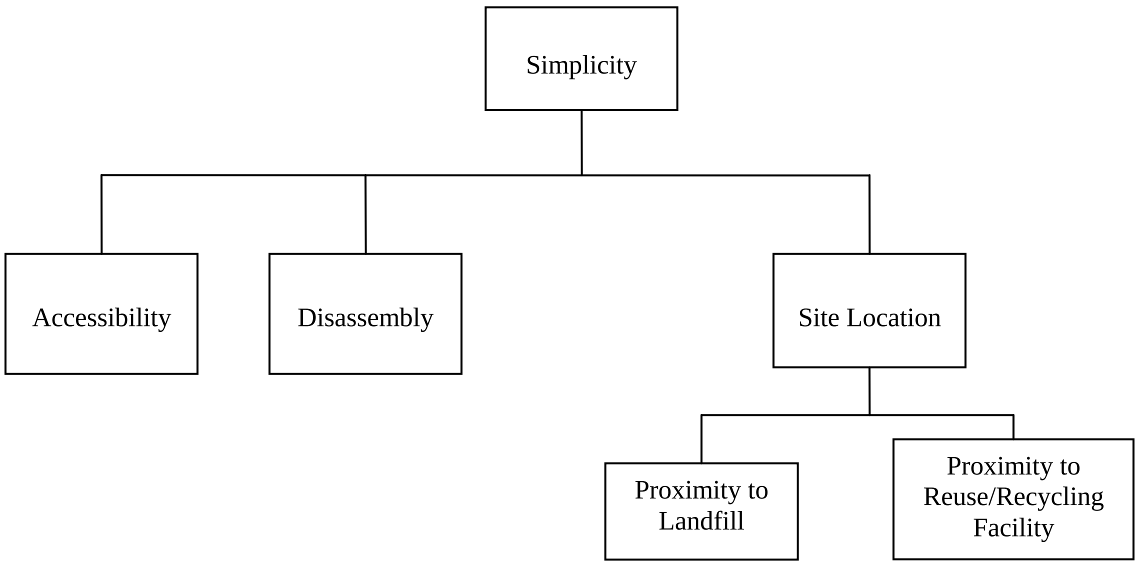


Figure 3.2. Value Hierarchy Branch for Simplicity

The decision maker felt that minimizing impact on the mission was an important factor to consider. Every military installation and military unit will have a mission, and it is the duty of the individuals of that installation or unit to seek to fulfill that mission each day. To the decision makers, an important consideration concerning the mission is the reason that the building has been identified for removal. Buildings that are being removed for a mission essential function are generally not good candidates because of the critical need for the land area. Specifically at Wright Patterson, some buildings have been identified for immediate removal to create spaces for C-5 operations. Due to the nature of the deconstruction process, it is much more time consuming and therefore a less

desirable removal option for buildings that must be removed quickly. A less significant impact on the mission is the inconvenience to base employees concerning parking or getting onto the installation. The decision makers, however, felt that these impacts were minor compared to the reason for the building's removal, so this first-tier value has no sub-values.

After mission impact, the decision maker felt that the potential for cost avoidance was another important factor when considering buildings for deconstruction. The decision makers identified two major methods of avoiding cost in a deconstruction project. The first is through the resale of the materials that were salvaged from the site. From a recent reuse and recycling project, the decision makers knew that the ability to sell these materials depends upon two factors: the quality of the materials and the local resale market for these materials. In addition to reselling the materials that were salvaged, another way to avoid cost is diverting waste from landfills. This reduces the total amount of waste that ultimately enters the landfill, which leads to the avoidance of landfill tipping fees. The hierarchy branch for Potential for Cost Avoidance is shown in Figure 3.3.

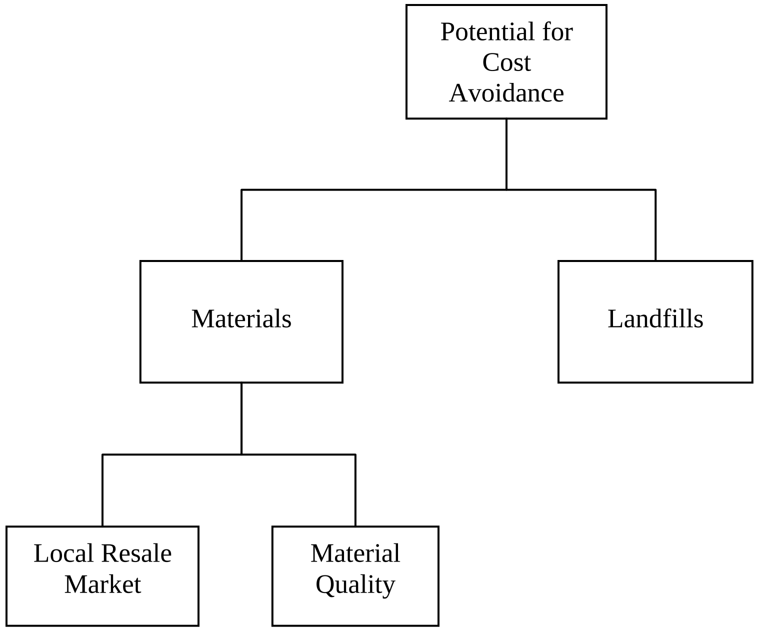


Figure 3.3. Value Hierarchy Branch for Potential for Cost Avoidance

The final first-tier value is minimizing environmental impact, which is defined as the reduction in activities that result in hazards for the environment. For the concept of deconstruction, minimizing the environmental impact is fulfilled by diverting demolition waste from landfills and back into new construction or recycling applications. Achieving a high diversion rate with deconstruction reduces the strain on primary materials and extends the life of landfills by diverting waste.

In this hierarchy, as well as the value hierarchies of many other problems, it is difficult to include cost because of independence issues. Often more valuable attributes of an alternative are more expensive; therefore, including cost in the hierarchy violates the decomposability principle discussed earlier. After a bid is accepted, the contractor is

then responsible for removing the building. When the Air Force determines that a building must be removed, bids for the contract are made by various contractors. Including a required diversion rate in these contracts drives up the price of removal and makes the idea of reusing and recycling the building materials less desirable. The decision makers for this model felt that it is more beneficial and cost effective to motivate the contractors to reuse and recycle the demolition debris after the contract is signed. The decision makers stated that some contractors salvage building components with no motivation from base personnel. These contractors recognize that diverting these building materials will ultimately save them money in disposal fees and that cost can be further avoided if the materials can be salvaged in good condition and resold. For other contractors, base personnel try to demonstrate that deconstruction can be a cost-effective option. The decision makers stated that this can be accomplished by showing the contractor information on the cost avoidance of successful deconstruction projects. Ultimately, the base achieves a reduction in environmental impact without increasing the cost of the contract. More explanation on the analysis of value versus cost can be found in Chapter 4.

Step 3: Develop Evaluation Measures

Each of the lowest tier values in the hierarchy is assigned at least one measure which evaluates how well an alternative fulfills the associated value (Kirkwood 1997: 24). For some values, more than one measure may be necessary or desired to fully represent the fulfillment of the objective. Measures can be either direct or proxy. A direct measure is one that directly measures the value of interest. An example would be

using miles to measure a “Distance” value. Conversely, a proxy measure represents the degree to which a value is achieved but does not directly measure the value itself (Kirkwood, 1997). Consider for example, an individual moving to another city who values “Cost of Living.” A direct measure for this value might be very difficult to determine; however, an appropriate proxy measure might be median house price, which would be easier to obtain. Although direct measures are generally preferred, proxy measures may be necessary for a variety of reasons. In many cases, data is simply not available or the value is too abstract for direct measurement.

Measures will have either a natural or constructed scale. A natural scale is one that is known and generally accepted and understood by all (Kirkwood, 1997). Examples are time, cost, length, distance, etc. A constructed scale is created for the specific purpose of evaluating the value and is less universal. These constructed scales are often categorical. For example, when buying a car, if one desires a sun roof, a constructed scale for this measure might be sun roof, moon roof, or none. The type of scale used will depend on the data available and the type of value that must be measured.

Measures should have three properties: measurability, operationality and understandability. Measurability means that a measure should only reflect the value in which the decision maker is interested (Keeney, 1992). A measure fulfills the principle of operationality if the definition allows for clear and exact evaluation of the alternatives with respect to that measure. Additionally, a value should exist for each point on the measure’s scale (Keeney, 1992). Finally, understandability suggests that the evaluation of the alternatives with respect to the measures should be clear and universal. Therefore,

one individual's evaluation of the alternatives with respect to the hierarchy should not be different from another person's evaluation (Keeney, 1992).

Measures for the lowest tier values in this hierarchy were identified by the decision makers. Table 3.2 shows the measures for the values under Simplicity, Table 3.3 shows the measures for Mission Impact, Table 3.4 shows the measures for the values under Potential for Cost Avoidance, and Table 3.5 shows the measures for Environmental Impact. Each table gives information on the type of measure, the definition, and the specific scale used.

Table 3.2. Measures for Simplicity

Lowest Tier Hierarchy Value	**Measure**	**Measure Type**	**Definition**
Accessibility	Parking Lot Space	Constructed, Proxy	The estimated available space surrounding the structure that could realistically be used for materials storage Categories: Minimal, Moderate Extensive
Deconstruction Simplicity	Type of Structure	Constructed, Proxy	The primary component of the building Categories: wood, brick, mixed, and concrete,
Proximity To Landfill	Miles to Landfill	Natural, Direct	Distance to the landfill, where disposal of debris that was not suitable for reuse will be disposed Units: Miles
Proximity to Recycling Facility	Distance to Recycling Facility	Natural, Direct	Distance to the reuse/recycling facility where the salvaged materials will be dropped off Units: Miles

Table 3.3. Measures for Mission Impact

Lowest Tier Hierarchy Value	Measure	Measure Type	Definition
Mission Impact	Time to Complete	Natural, Proxy	Time from beginning of project until the site is cleared Units: Weeks
	Need for Site	Constructed, Direct	How immediate the need is for the building's site Categories: No Need, Non Urgent, Urgent, Immediate

Table 3.4. Measures for Potential for Cost Avoidance

Lowest Tier Hierarchy Value	Measure	Measure Type	Definition
Local Resale Market	Local Resale Value of Wood	Natural, Direct	Price that can be expected for one ton of salvaged wood in the local market Units: $/ton
Estimated Material Quality	Year Built	Constructed Proxy	The year that the structure was built Units: Year Completed
Landfill Cost	Local Tipping Fee	Natural, Direct	The tipping fee per ton of waste for the landfill that debris that is not salvaged will go to Units $/ton

Table 3.5. Measures for Environmental Impact

Lowest Tier Hierarchy Value	Measure	Measure Type	Definition
Environmental Impact	Diversion Rate	Natural, Direct	The percentage of the waste by weight that can be diverted from landfills Units: percentage
	Waste Diverted	Natural, Direct	The amount of waste that can be diverted from landfills Units: tons

Step 4: Create Value Functions

Data collected for each of the measures, for each of the alternatives, must be combined in such a way that allows the decision makers to see which alternatives best fulfill the objectives identified in the hierarchy. Of the inherent problems that arise when combining measure scores to determine an overall score for an alternative, the most pressing issue is the varying units used with the measure. The solution for this problem is to use the multi-objective value function. For this method, a single dimensional value function must be created for each measure in the hierarchy. A value function for a given measure is a graph in which the *y*-axis has a value range of 0 to 1 and the *x*-axis consists of the measure's scale. Therefore, the value function converts a measures score into a unit-less value between 0 and 1. A score of zero represents the least desired value of the measure, while a score of 1 represents the most desired value (Kirkwood, 1997). After the single dimensional value functions are determined, the converted value units are combined with the weights to form an overall score. This process is discussed further in Chapter 4.

Each value function was one of the following types: categorical, monotonically increasing, or monotonically decreasing. A categorical value function is basically a bar graph. The *x*-axis will have discrete categories and the *y*-axis will have a value associated with that category. An example of a categorical value function is the color of a car. The *x*-axis will consist of various colors that are options for a car, and the *y*-axis will have a value associated with each color. A monotonically increasing value function is a line graph that is increasing over the *x*-axis. This implies that, for the measure, more is always better. An example of a measure that produces a monotonically increasing value function is profit. A monotonically decreasing value function is a line graph that decreases over the *x*-axis. This implies that less is better. An example of a measure that produces a monotonically decreasing value function is cost.

For this analysis, a single dimensional value function was created for each measure. For categorical measures, the decision makers were asked to identify which of the given categories were the most and least desirable; they were then queried about the relative importance of the other categories compared to the most and east desired ones. For other measures, the decision makers were asked to identify the most and least desirable scores measures, which were given a value of 1 and 0, respectively. The decision makers were then asked about their preference over the range of the measure, to determine the incremental changes in value in along the graph. For example, when determining the value function for "Time to Complete," the decision makers were asked, "Is a decrease in the time to complete from 5 weeks to 4 weeks better than a decrease from 21 to 20 weeks?" An answer of yes suggested that as the building takes longer to deconstruct, the decision maker cares less about each additional week. The opposite

should also be true; at the lower end of the scale, the decision maker cares more about each additional increase in the time to complete. Questions like this were asked along the entire scale until the decision maker's preference across the entire range was determined. "Are you equally happy with a completion time of 23 weeks as you would be with a completion time of 25 weeks?" was another example of a question that was posed to the decision makers. The resulting value functions created are shown in the figures below.

Figure 3.4 shows a categorical value function; rather than a range of numbers, the *x*-axis consists of three categories which the decision makers were sufficient to accurately measure the accessibility of a building site. Extensive parking lot space allows for easier worker access to the site as well as more storage space for materials as they are removed from the building and sorted. A moderate amount of parking lot space suggests that the site is relatively open but is not surrounded by a large amount of open area. A minimal amount of parking lot space suggests little to no access to the building and generates a value of 0 because it makes the deconstruction process much more difficult.

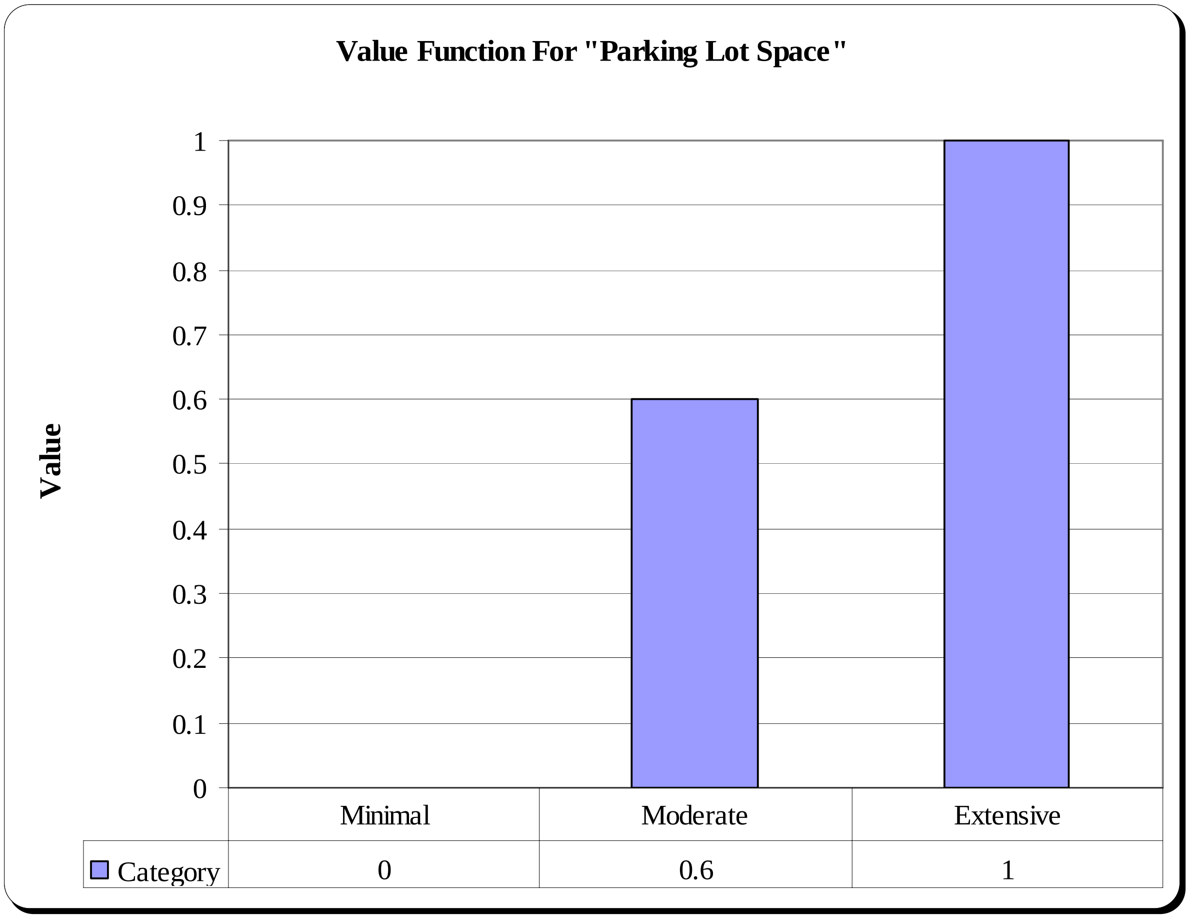


Figure 3.4. Value Function for Parking Lot Space

Figure 3.5 shows the value function for the type of structure. The decision makers communicated that there are four basic construction types for buildings on Wright Patterson Air Force Base. From experience, the decision makers know that wood buildings are the easiest to deconstruct, so having a building structure that is composed primarily of wood generates a value of one. Brick structures are less simple and the ease of disassembly depends largely on the type of mortar used. Concrete structures can be

very difficult to take apart. If the structure does not have a single material as its primary composition, it was identified as mixed construction. Although ease of deconstruction depends on the specific types of materials found in a mixed construction building, the decision makers felt that, on average, the ease of disassembly would be approximately the same as the ease of disassembling a brick structure.

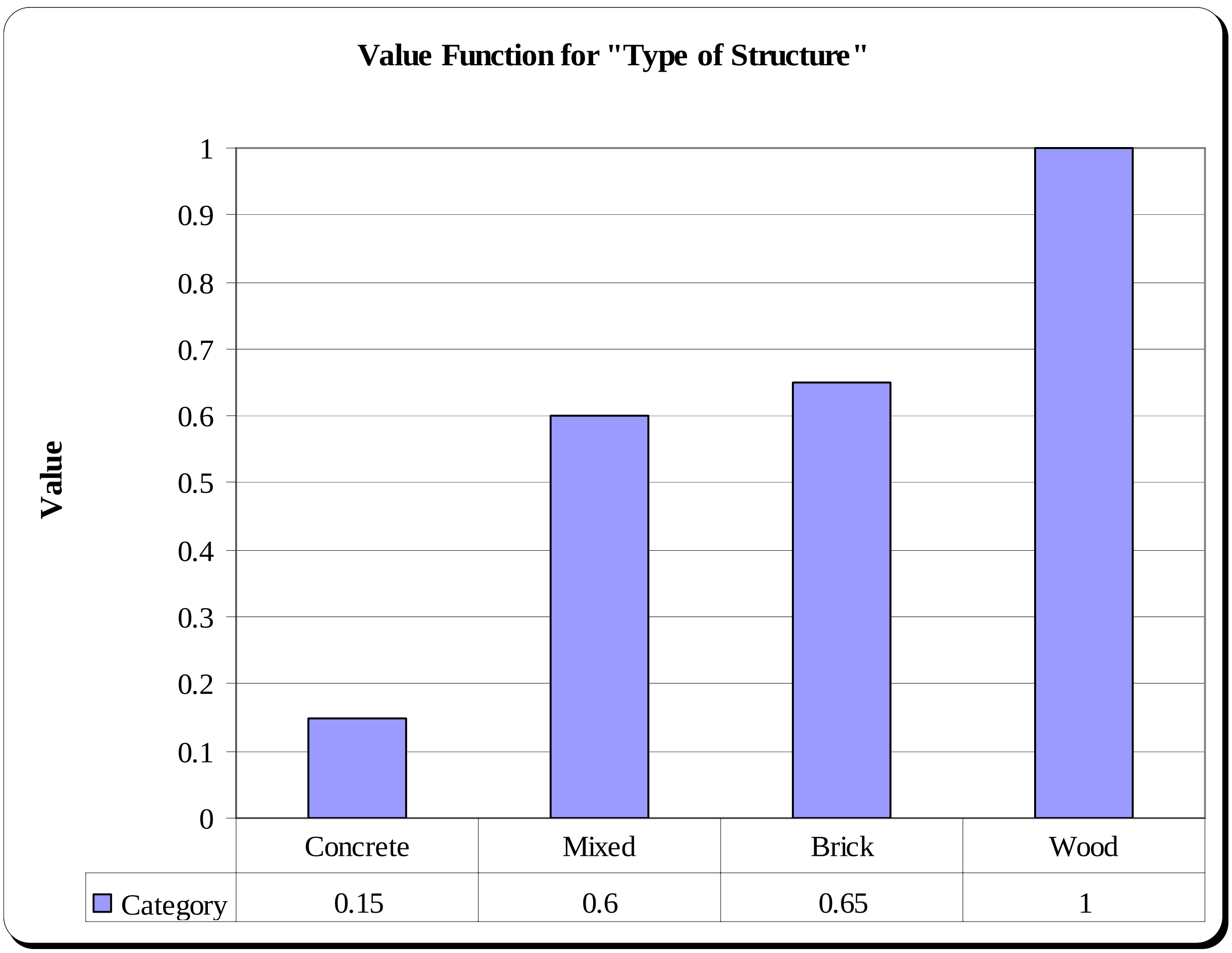


Figure 3.5. Value Function for Type of Structure

Figure 3.6 is an example of a monotonically increasing value function. For the range of the *x*-axis, the value is always increasing. The decision makers felt that if a landfill is further from the building site, then deconstruction of the building is a more desirable removal option because it minimizes transportation cost to the landfill. The graph above is exponential, which means that an increase of one mile in distance on the lower portion of the range will have a different increase in value than a one mile change on the higher end of the range.

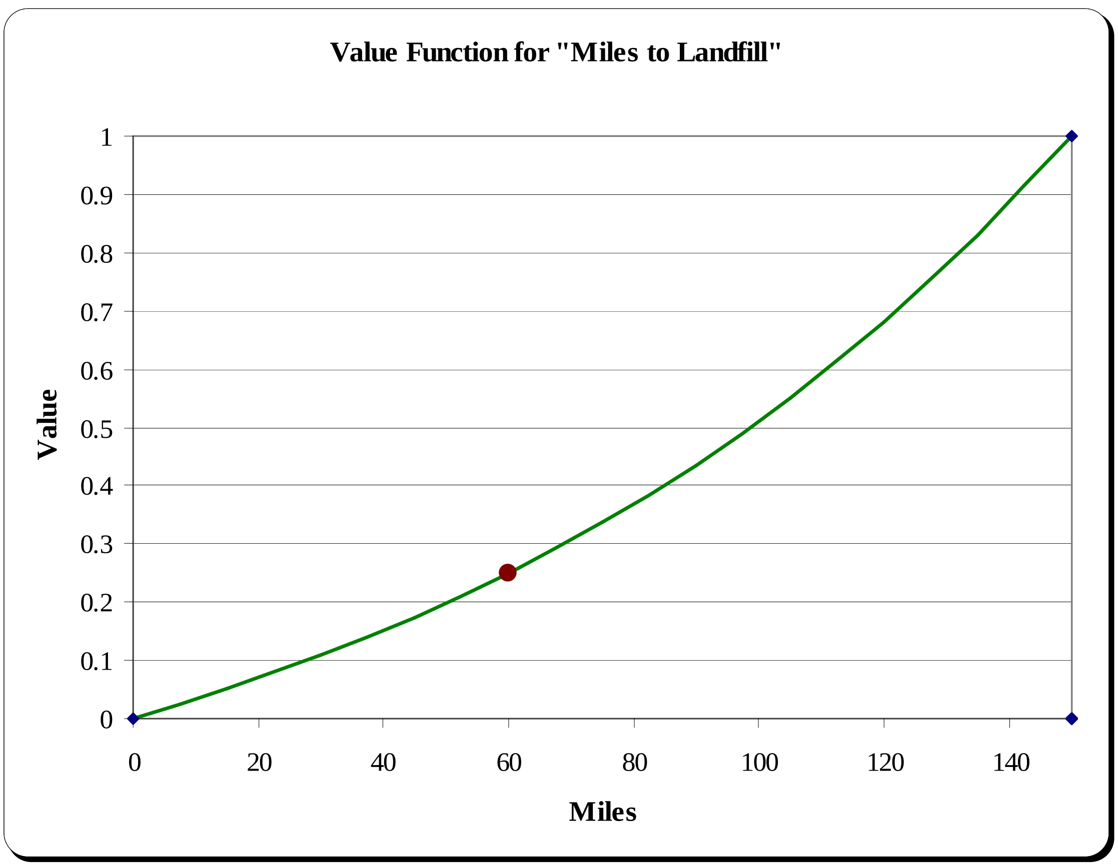


Figure 3.6. Value Function for Miles to Landfill

Figure 3.7, an example of a monotonically decreasing value function, is approximately the opposite of the value function for "Miles to Landfill." For most bases, the intended landfill for the construction and demolition waste will be less than 60 miles away, but the decision makers wanted to be able to analyze buildings in other areas. The range extends to 150 miles to account for buildings that may be in remote areas of the country, where a construction and demolition landfill would be much farther away.

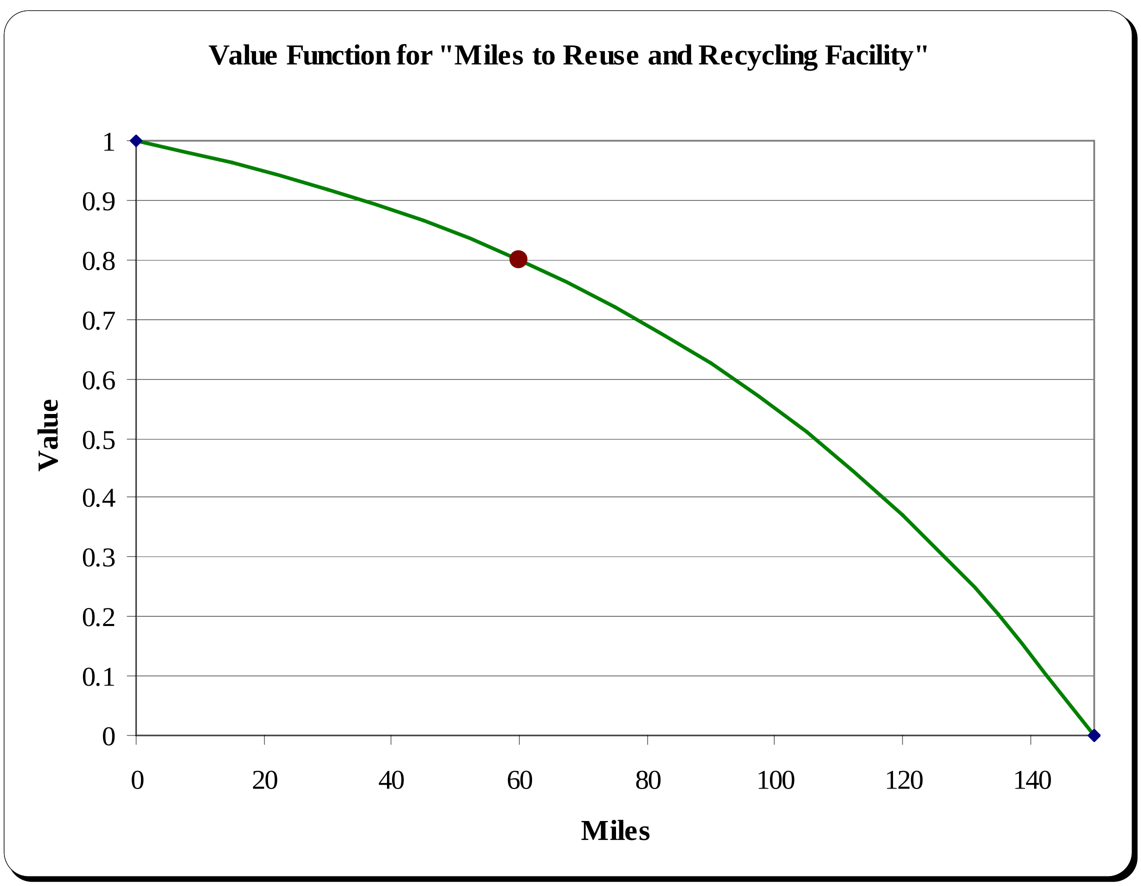


Figure 3.7. Value Function for Miles to Reuse and Recycling Facility

Figure 3.8 is another example of a monotonically decreasing value function. If a building will take more time to deconstruct, it will generate a lower value for this measure. For this measure, the value drops dramatically over the range from 0 to 8 weeks. The decision makers felt that a deconstruction project that takes longer than 8 weeks would be a less desirable candidate. Some of the larger facilities on Wright Patterson Air Force base are tens of thousands of square feet in size. The time to deconstruct these buildings will be closer to the right part of the graph in Figure 3.8. At approximately 40 weeks, the graph levels out at zero value.

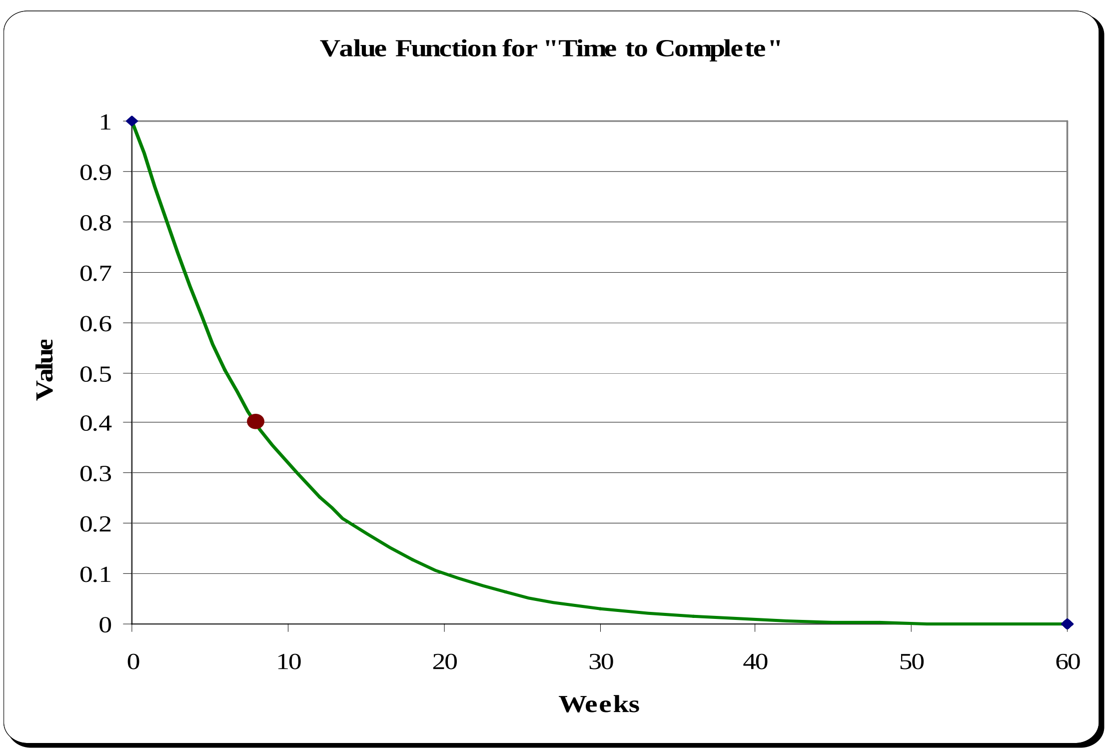


Figure 3.8. Value Function for Time to Complete

Figure 3.9 shows that if there is no need for the building site, the alternative will get the full value for this measure. The decision makers felt that the need for the building site could be accurately measured using the four indicated categories. If the need for the site is immediate, then the building will get no value. An urgent need for the building site suggests that the site is needed in the very near future but not immediately. A non-urgent need suggests that the building is not needed in the very near future, but the site will eventually need to be cleared for another purpose.

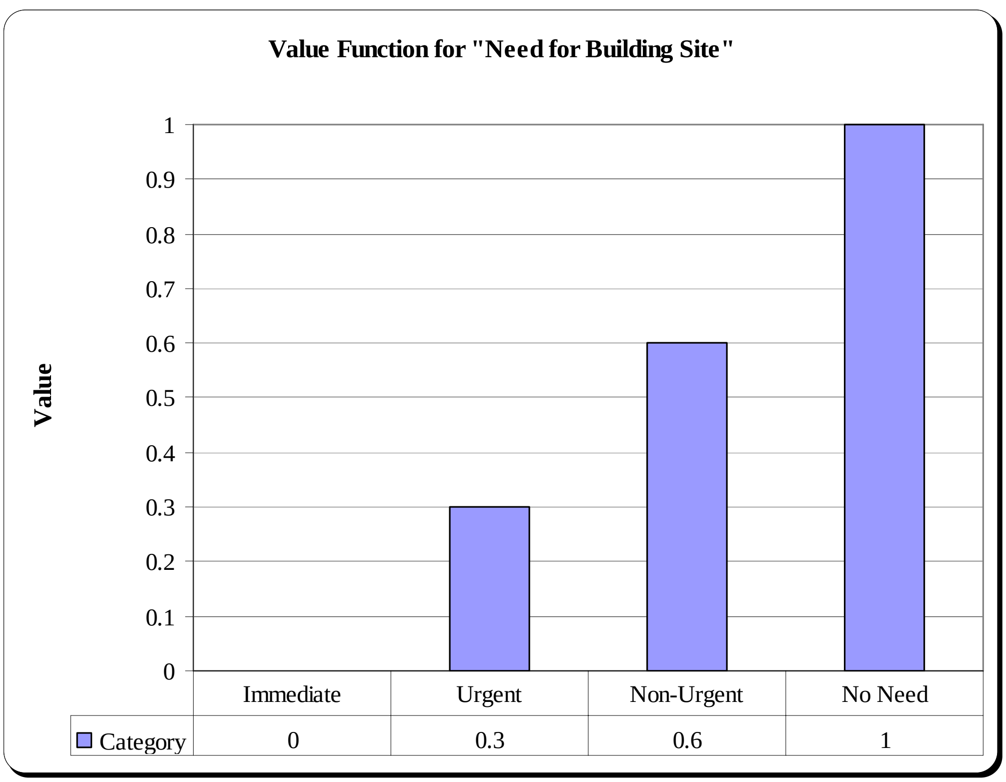


Figure 3.9. Value Function for Need for Building Site

In Figure 3.10, the value increases relatively quickly between $0 and $40 per ton. After $40 per ton, the rate of increase slows slightly until a tipping fee of $100 per ton results in a value of 1. Rare woods in excellent condition, such as the one discussed in the literature review, would be expected to achieve resale values on the higher end of the range. The decision makers felt that $40 per ton was slightly higher than average.

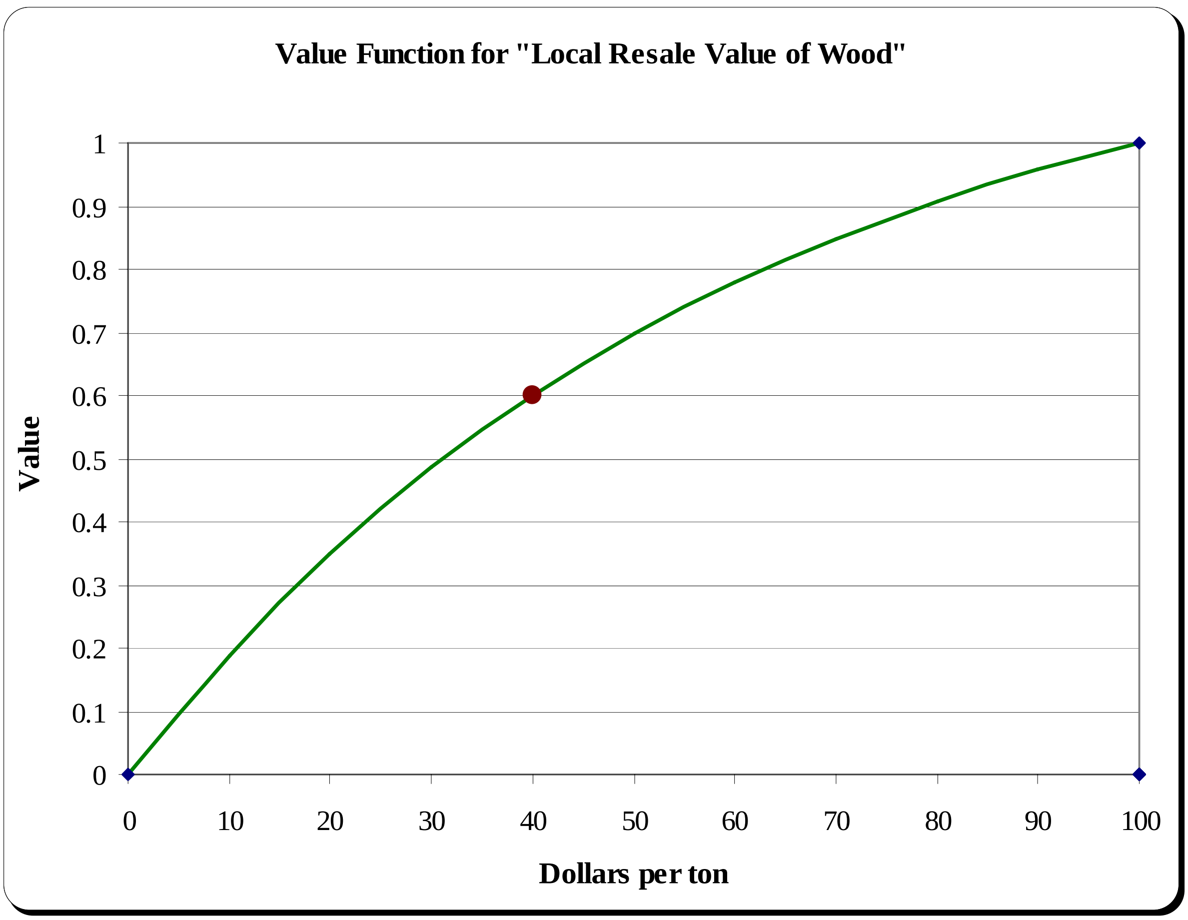


Figure 3.10. Value Function for Resale Value of Wood

Figure 3.11 demonstrates the decision maker's preference for buildings that were constructed before World War II. From experience, the decision makers knew that buildings constructed during that time can be expected to contain high quality materials, including some of the rare and valuable materials discussed in the literature review. Any structure built before 1950 had a value of at least 0.85 for this measure. Newer buildings had a much lower value for this measure.

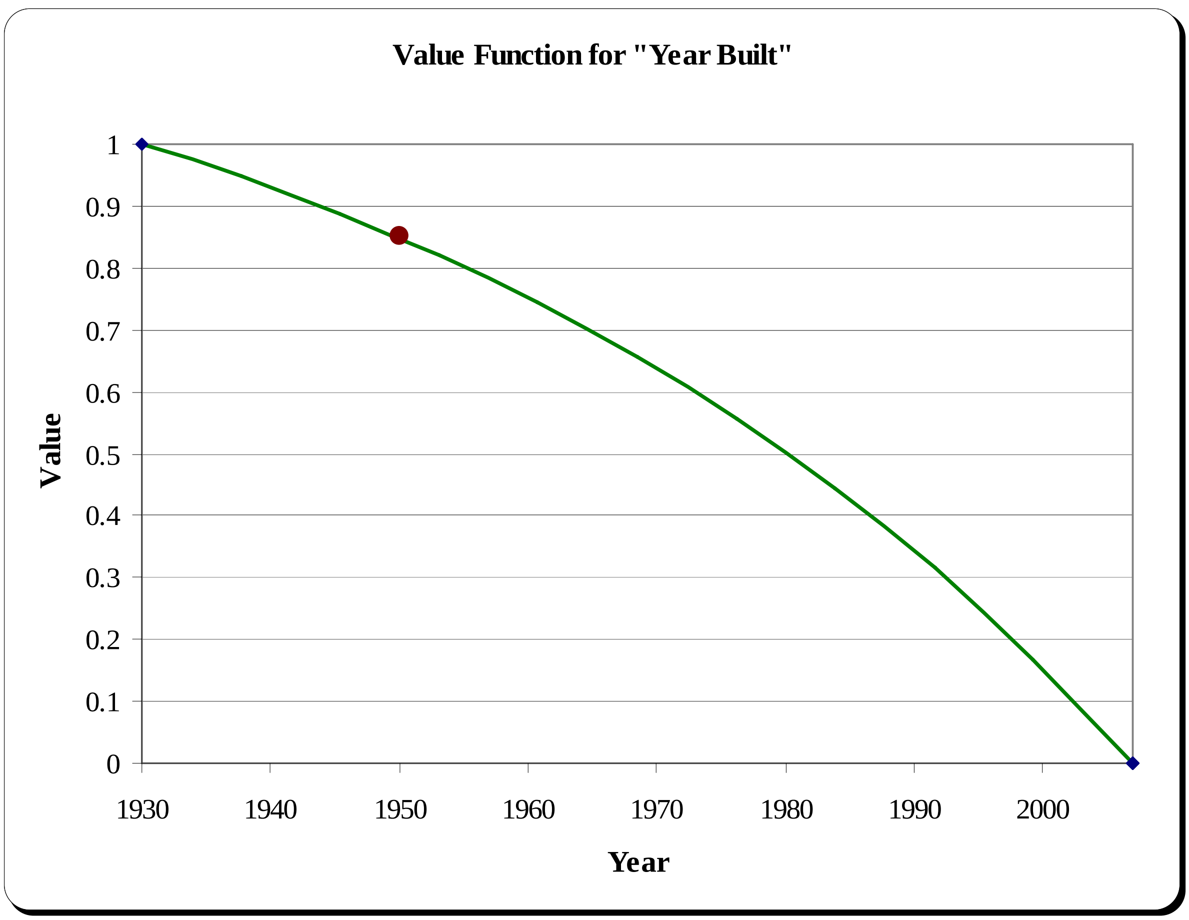


Figure 3.11. Value Function for Year Built

Figure 3.12 demonstrates the decision maker's preference concerning the local tipping fee. A higher tipping fee increases the appeal of deconstruction. High tipping fees mean that diverting waste from landfills will result in greater cost avoidance. Many urban areas experience tipping fees on the higher range of costs. From $0 to $60, the incremental increase in value is slightly higher than it is between $60 and $100.

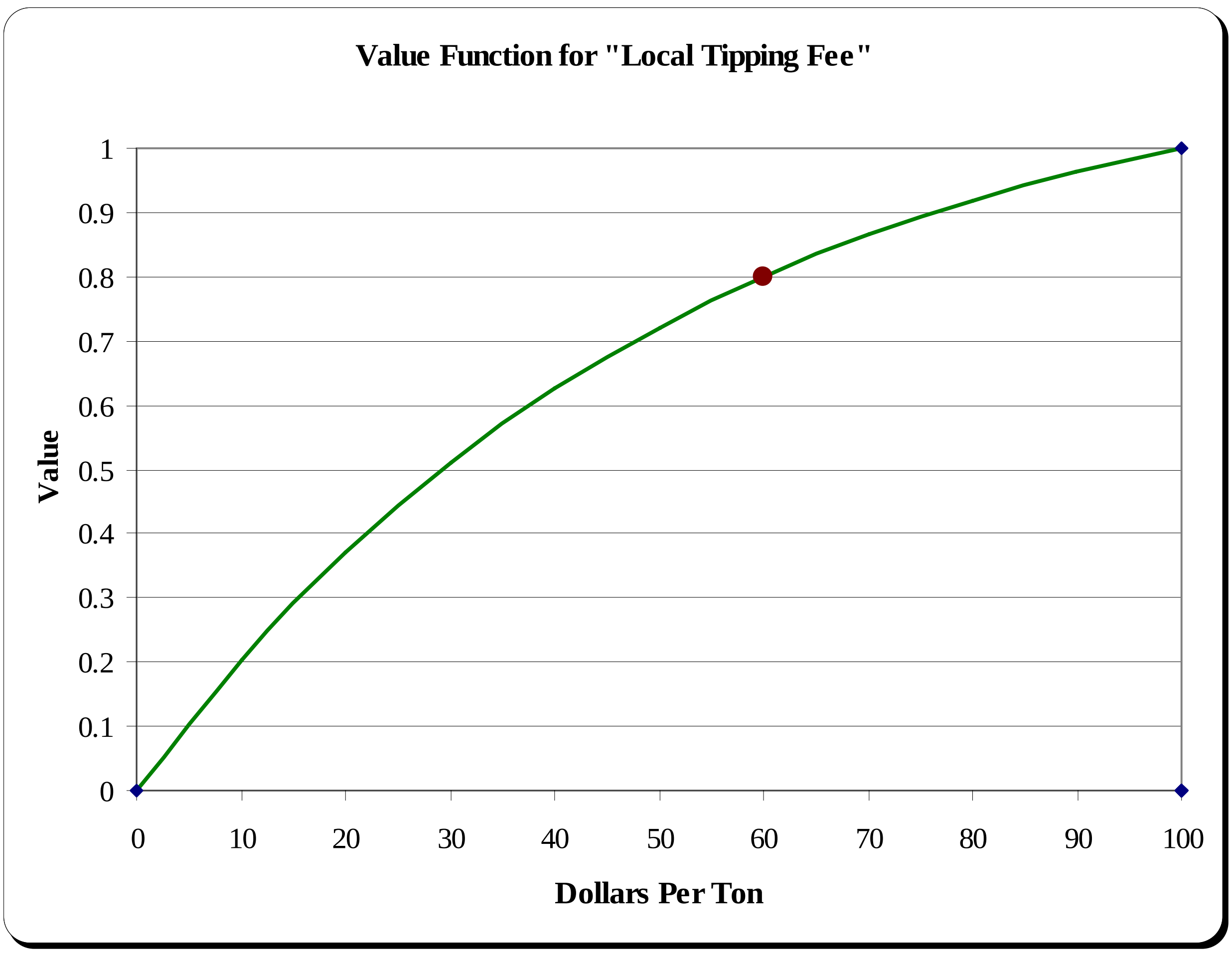


Figure 3.12. Value Function for Local Tipping Fee

The value function shown in Figure 3.13 is almost linear. Traditional demolition and landfilling of the waste results in a diversion rate of 0 percent, which the decision makers have assigned a value of 0. This means that they have no preference for no diversion with respect to this measure. The slight curve demonstrates that the increase from 0% to 75% is slightly faster than the increase from 75% to 100%.

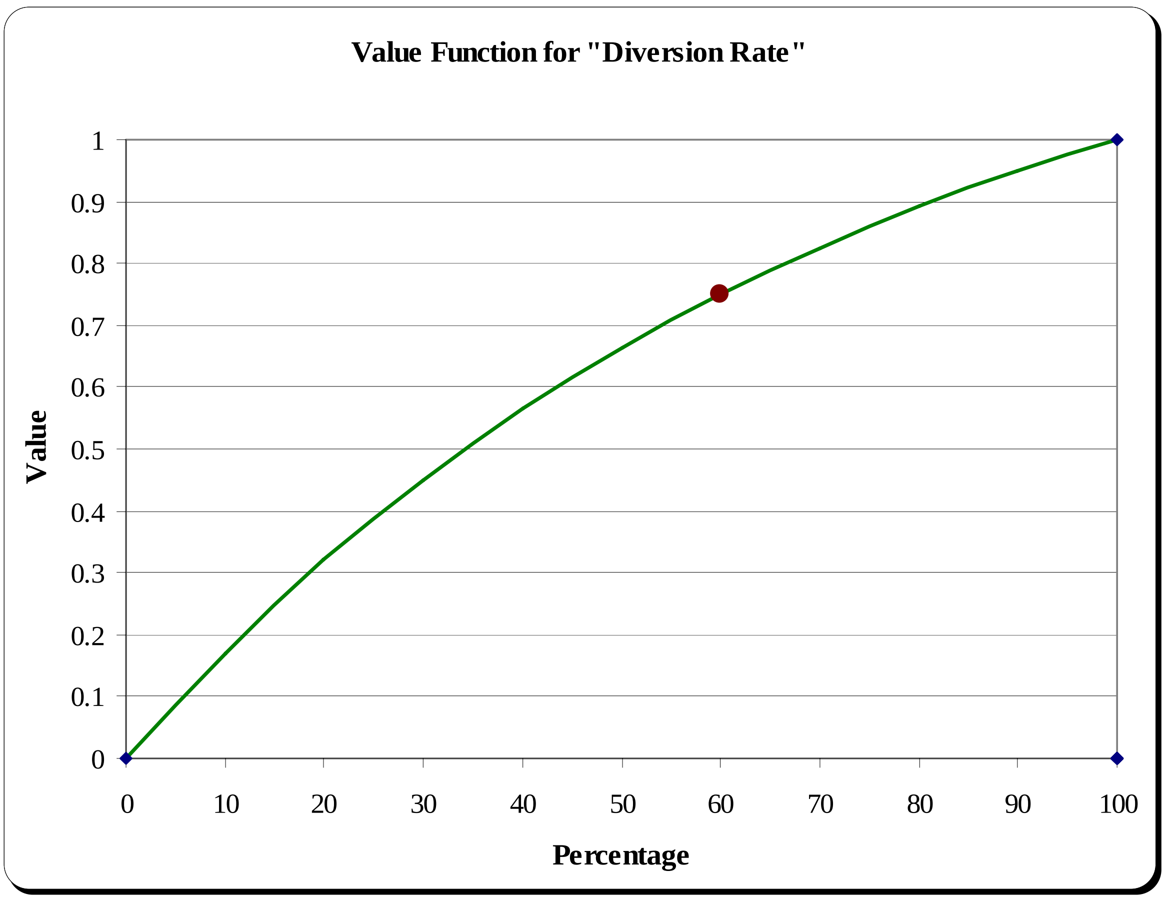


Figure 3.13. Value Function for Diversion Rate

Figure 3.14 shows that the decision makers prefer more diversion of waste. If 500 tons or more can be diverted from the project, then the decision makers will have a value of 0.5. The increase in value over the range of 0 to 500 is more drastic than the increase in value over the rest of the graph.

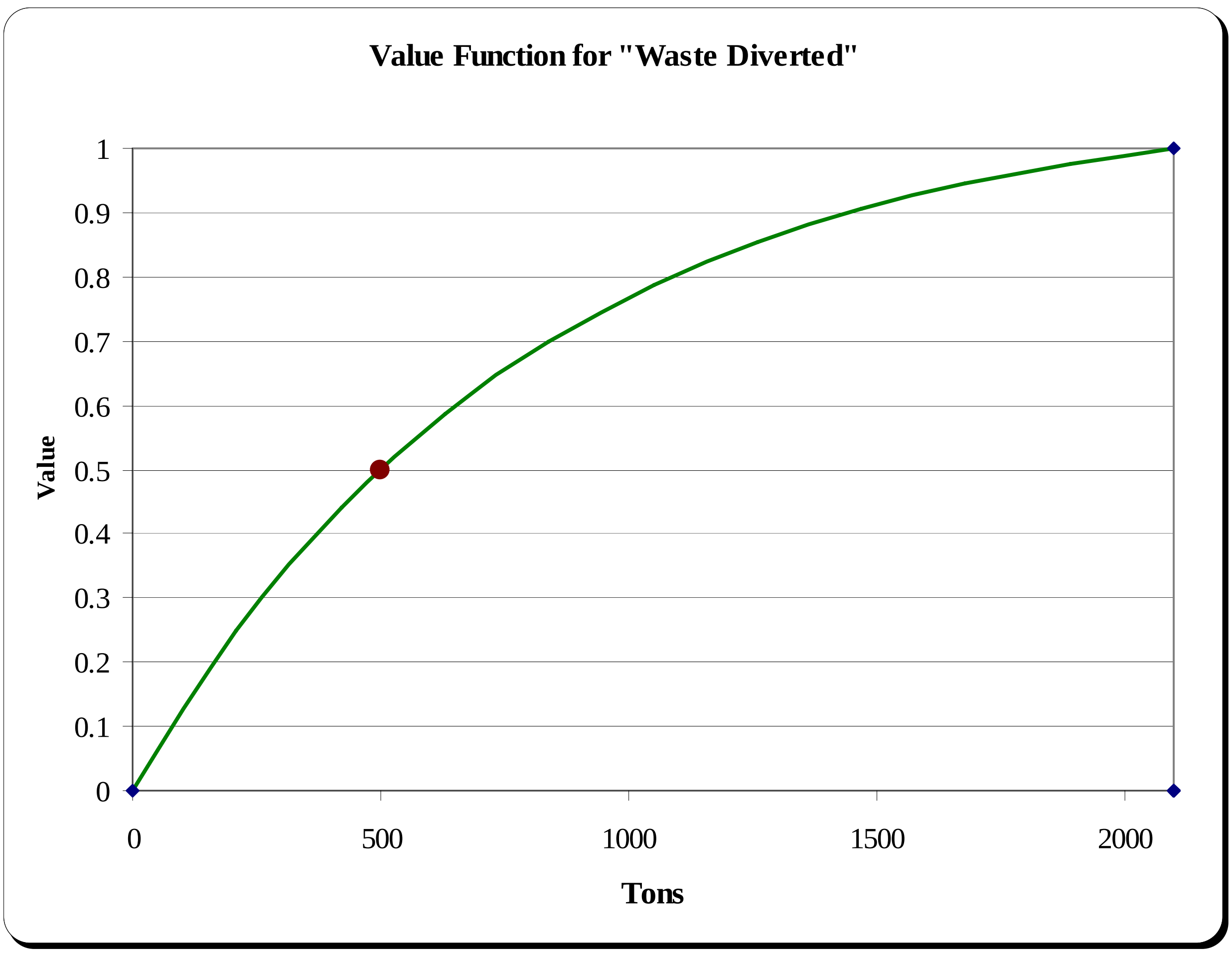


Figure 3.14. Value Function for Waste Diverted

Step 5: Weight Value Hierarchy

The decision maker must assign weights to each value and each measure. The weight is an indication of the degree of importance associated with each value and measure in the hierarchy. Both local and global weights for values in the first tier must sum to one; sub-values in the same tier, within the same branch, must have local weights that sum to 1. For this hierarchy, the decision makers were asked to rank the top tier values in order of their importance. They determined that Mission Impact is the most important value followed by Potential for Cost Avoidance, Simplicity, and Environmental Impact. The decision makers were then asked about the importance of each value relative to the other first-tier values. The resulting weights for the first-tier values are shown in Table 3.6.

Table 3.6. Weights for First Tier Values

Value	**Weight**
Simplicity	0.25
Mission Impact	0.35
Potential for Cost Avoidance	0.30
Environmental Impact	0.10

The same process was used to generate local weights for the lower tier values. If one of the lowest tier values had more than one measure, weights for the measures were

also determined.   The local weight of a value refers to the value's importance relative to other values in the same tier under the same value; the same concept applies for measures. Global weights refer to the weight of the value relative to all other values in the hierarchy. The local and global (shown in parentheses) weights for each value are shown in Figures 3.15, 3.16, 3.17, and 3.18. The overall value hierarchy is shown in Appendix A.

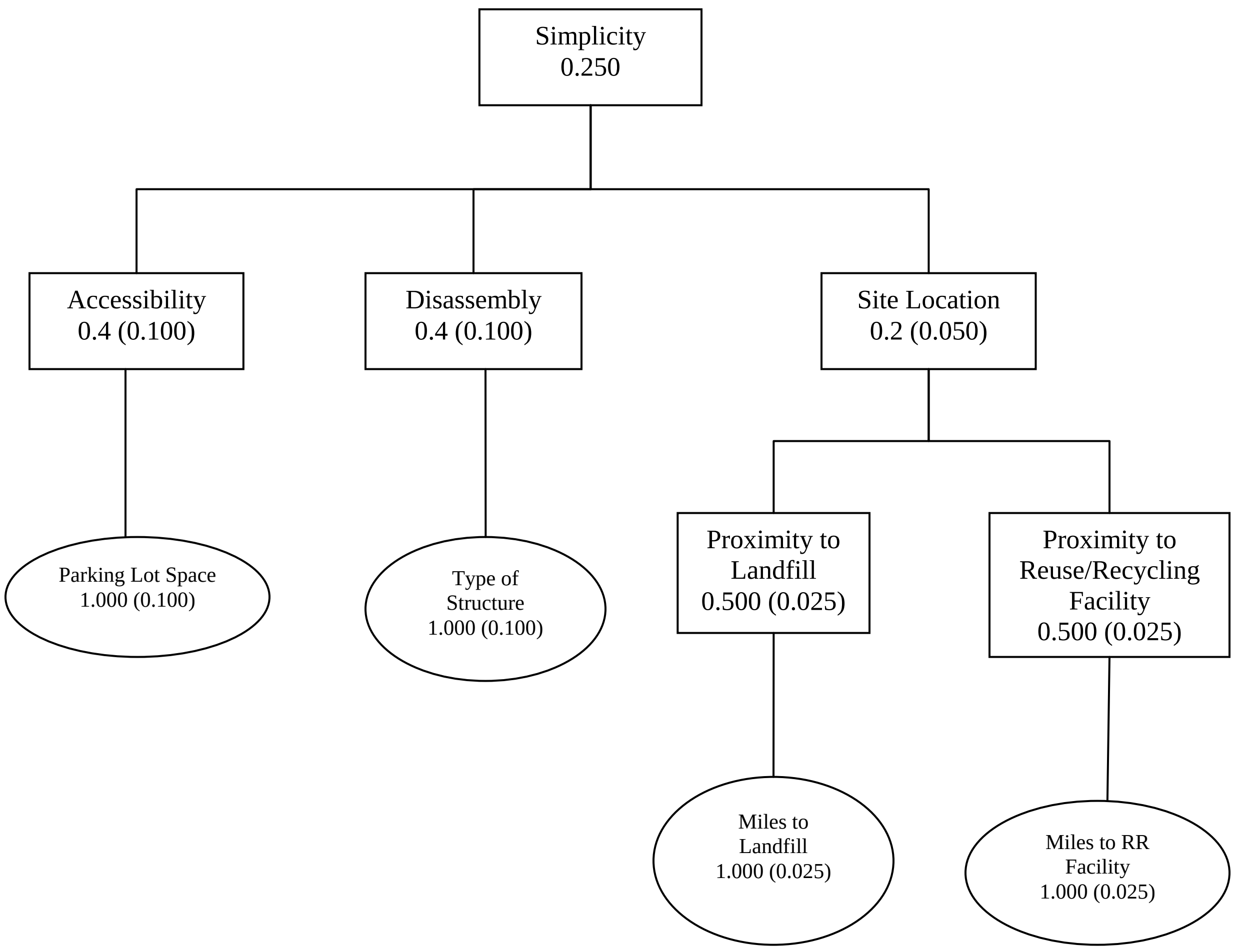


Figure 3.15. Value Hierarchy Weights for Simplicity

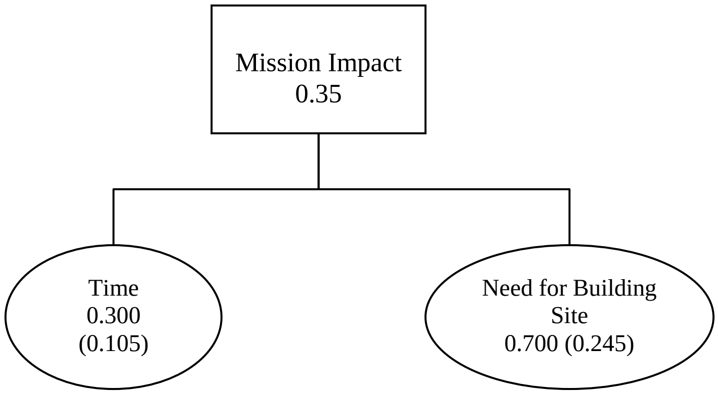


Figure 3.16. Value Hierarchy Weights for Mission Impact

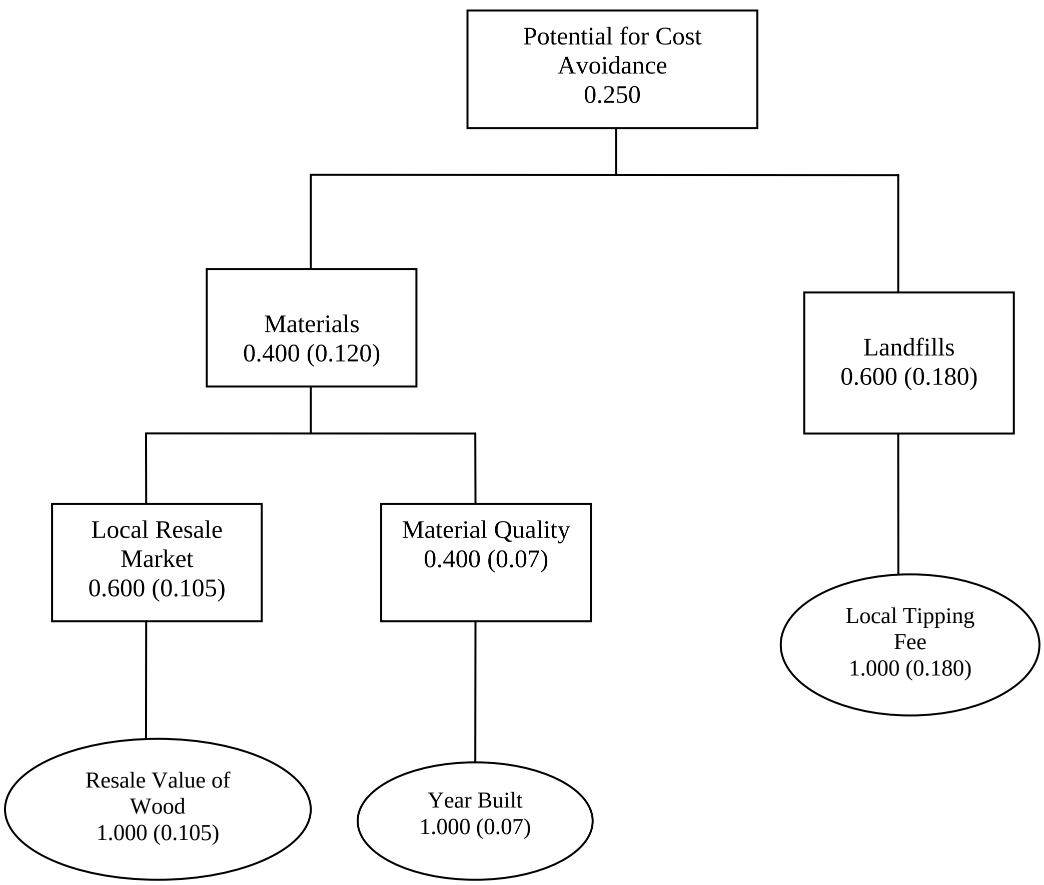


Figure 3.17. Value Hierarchy Weights for Potential for Cost Avoidance

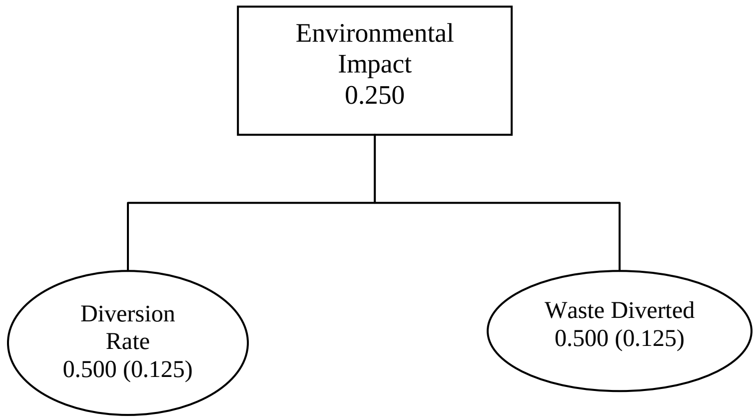


Figure 3.18. Value Hierarchy Weights for Environmental Impact

Step 6: Alternative Generation

The alternatives people usually identify for a given decision are usually the most obvious ones that first come to mind (Keeney, 1992). A major advantage of Value Focused Thinking as a decision making tool is the fact that it facilitates the identification of new and creative alternatives. One method of doing this is to examine the evaluation measures of the hierarchy and identify alternatives that generate a high value for a given measure. For example, in this case, if the base wanted to examine more buildings for their deconstruction potential but did not want to waste time analyzing bad candidates, they might start by looking at all wood-framed buildings or the buildings with the most parking lot space. In addition to using the measures to identify new alternatives, the values, especially the first-tier values, can also be used. In many cases, like this one, more creative alternative generation is not necessary because the alternatives are already established. Thus, the alternatives for this value focused thinking model are buildings

that have been identified for removal on Wright Patterson Air Force Base. Table 3.7 shows the building number, type of facility, and square footage of the buildings that will be analyzed for this research.

Table 3.7. Alternatives

Building Number	Facility Type	Square Feet
20464	Area B Gas Station	2336
31230	Temporary Living Facility	5576
31231	Temporary Living Facility	3548
31232	Temporary Living Facility	5314
31233	Temporary Living Facility	3992
31223	TLF Storage Facility	867
20682	Library of Congress Facility	7366
30251	Hazardous Material Storage Shed	432
20447	Aircraft Research Lab	1630
20449	Aircraft Research Lab	2480
34042	Reserve Forces Training Facility	33032
11435	Vet Clinic	2299
11405	Communications Admin Building	10372
11400	Communications Admin Building	5546
11401	Communications Storage Facility	3813
20126	AU Prof/Tech Ed	34180
20055	Engineering Admin.	6471
20130	Communications Hut	324

Step 7: Alternative Scoring

The first step in scoring the alternatives is to collect the necessary data. The data for each alternative in Table 3.7 is shown in Appendix B. Using the value functions created in Step 4, this data is converted into a value. The following discussion provides information on how the data for each measure was obtained or determined.

Wright Patterson Air Force Base maintains building records which provided data for the type of structure, the need for the building site, and the year built. These building records were provided by the Base Civil Engineering Management division. The need for the building site was provided by Wright Patterson Air Force Base's strategic plan.

The data for both the time to complete and the amount of waste diverted were calculated based on the square footage of the building structure and published literature. From the literature, one article stated that three to five square feet per labor hour is a relatively accurate estimate for the time required for building deconstruction (Webster, 2003). Additionally, the University of Florida performed a building deconstruction experiment and found that 0.291 labor hours were needed per square foot of building space (Guy, 2000). The more conservative estimate of three square feet per labor hour was used in this analysis. Again, using published literature, the square footage of the house was converted into tons of debris so that the amount of waste diverted could be examined. The Military Base Closure Handbook claims that 72 pounds of building material per square foot of building space can be expected for residential demolition (Moulton-Patterson, 2002). Additionally, estimates were found in the literature that residential housing will produce between 111 and 127 pounds per square foot of building space while non-residential demolition will produce 155 pounds per square foot of

building space (Franklin Associated, 1998). For this research, a value of 100 pounds per square foot of building space was used for the Temporary Living Facilities (TLFs), while a value of 155 pounds per square foot was used for the non-residential facilities.

In addition to calculating data, some of the information was obtained by examining each individual building. For the parking lot space of each structure, the building site was visited and photographs of each building were examined to determine the approximate available parking lot space. This process was completed with the assistance of the Base Civil Engineering Management division. In the same way, the distance to both the local construction and demolition landfill and the reuse and recycling facilities were found using the individual addresses of the building sites. The distance was determined using driving direction software on the internet using the address of the building and the address of the landfill and reuse facility. This process produced the exact driving distance from the building site to both the landfill and the reuse facility.

The local resale value and tipping fees were determined by calling each facility. The Xenia Demolition Debris Facility had an average tipping fee of $28 dollars per ton of waste. The local resale value of wood was more difficult to determine because the contractors and companies that accepted demolition wood waste were reluctant to name an exact price without first surveying the building structure. They did however state the range that could be expected was between $10 and $26 per ton. This range produces an average value of $18 per ton, which was used in this analysis.

The final measure is the percent diverted. Deconstruction can produce high diversion rates; while this diversion diminishes the environmental impact of building removal, it drives up the cost of the removal contract. The decision makers set the

diversion rate for residential buildings at 90% and the rate for non-residential buildings at 80%. Based on experience, the decision makers felt that this was the maximum diversion rate that could be achieved for each type of structure.

Chapter 4. Results and Analysis

Introduction

The purpose of this chapter is to analyze the information that was generated in Chapter 3. An overall value was determined for each alternative and the alternatives will be ranked. The alternatives with the highest values are the most preferred deconstruction projects based on the decision maker's values. A sensitivity analysis was also performed to see how sensitive the results are to changes in weights of the hierarchy.

Step 8: Deterministic Analysis

For each of the alternatives, the scores from the measures are combined to form an overall value. This value represents how much the alternative fulfills the objectives of the decision maker (Kirkwood, 1997). The overall value is the sum of the values of each measure multiplied by the global weight. The overall values for each alternative are shown in Figure 4.1.

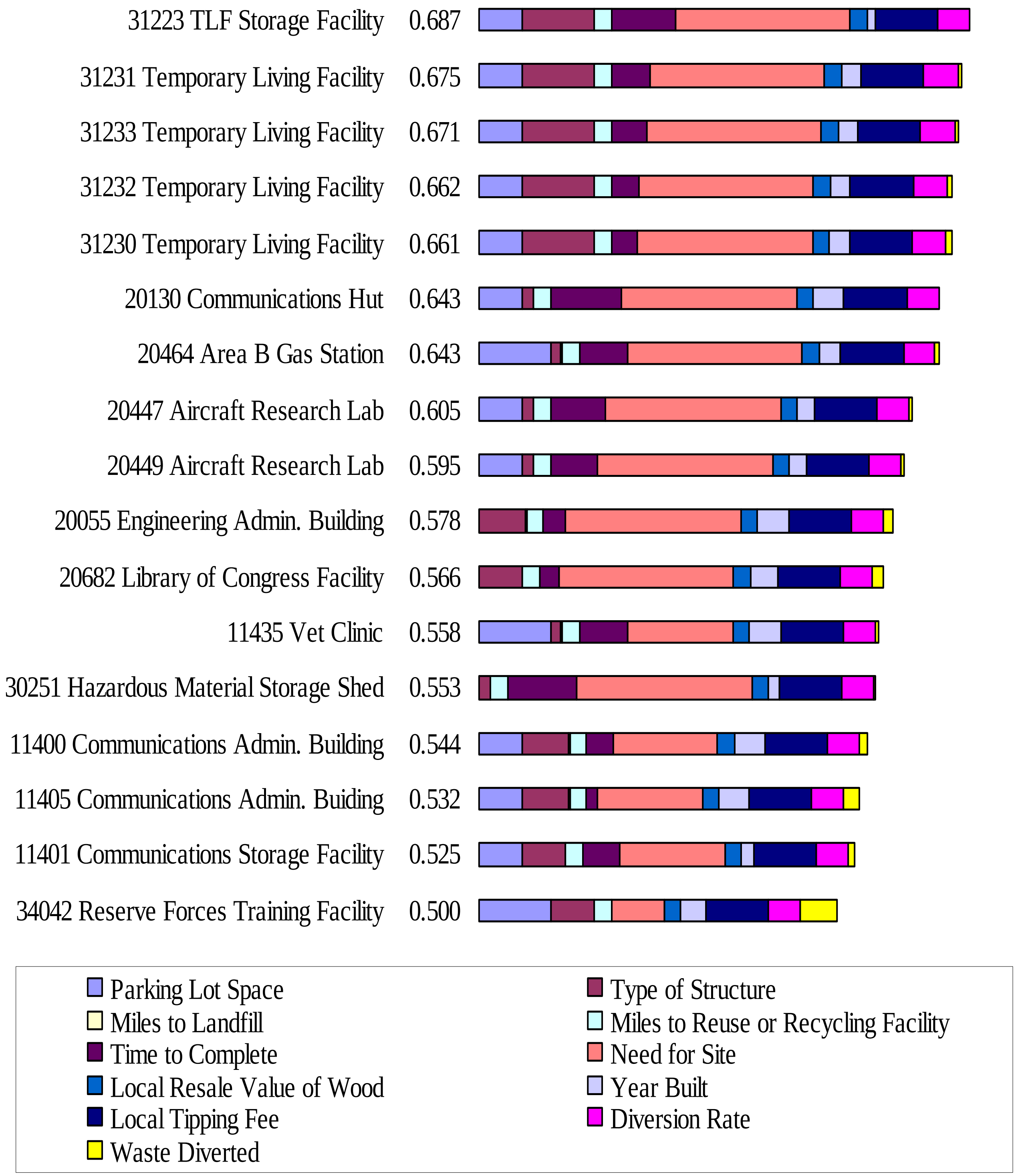


Figure 4.1. Overall Values for Alternatives

Figure 4.1 shows that the Temporary Living Facilities (TLFs) are the best deconstruction candidates based on the values of the decision makers. Their high ranking is primarily the result of two reasons. First, their relatively small size results in a faster deconstruction time and subsequently a reduced mission impact, which is the most heavily weighted first-tier value. Furthermore, these facilities are the only buildings that are wood framed, which gives them the full value for simplicity of disassembly.

Because the buildings are all structures at Wright Patterson Air Force Base, certain measures produced the same value across all of the alternatives. These were still included because the decision makers wanted to use the model to examine how the deconstruction potential of structures at Wright Patterson compare to the potential of structures in other areas. The local resale value of wood and the local tipping fees were the same for all alternatives because the debris from each of the buildings will enter the same landfill and the salvaged materials would go to the same reuse and recycling facility. In the same way, the distance to the landfill and the reuse and recycling center varied, but not significantly. Although the exact distance was determined for the sake of accuracy, the distance varied a few miles at most. Finally, for the sake of analysis, an 80% diversion rate was used for all of the alternatives. Assuming all other factors remain the same, the ranking of the alternatives based on the decision maker's values do not change if the diversion rate for all of the structures is set at 90% or 70%.

The final component of the deterministic analysis is to analyze the value produced by the alternative with respect to cost. As stated before, including cost in the value hierarchy raises independence issues. However, cost is a factor that cannot be ignored for this and for most decisions. A way to factor cost into the value focused thinking process

without compromising the independence of the value hierarchy is to perform a cost-value analysis. The value of the alternative is divided by its respective cost to produce a value to cost ratio. The costs used are the expected demolition contract costs. The results of this portion of the data analysis are shown in Table 4.1

Table 4.1. Cost-Value Analysis of Alternatives

Facility	Value	Cost (in thousands)	Value/Cost
31223 TLF Storage Facility	0.687	$18.80	0.03654
30251 Hazardous Material Storage Shed	0.553	$22.00	0.02514
11401 Communications Storage Facility	0.525	$39.00	0.01346
20447 Aircraft Research Lab	0.605	$59.50	0.01017
20449 Aircraft Research Lab	0.595	$62.40	0.00954
20464 Area B Gas Station	0.643	$100.00	0.00643
11400 Communications Admin. Building	0.544	$100.00	0.00544
31233 Temporary Living Facility	0.671	$123.50	0.00543
20130 Communications Hut	0.643	$130.00	0.00495
11435 Vet Clinic	0.558	$141.80	0.00394
31231 Temporary Living Facility	0.675	$178.00	0.00379
20055 Engineering Admin. Building	0.578	$175.00	0.00330
31232 Temporary Living Facility	0.662	$224.60	0.00295
31230 Temporary Living Facility	0.661	$253.80	0.00260
20682 Library of Congress Facility	0.566	$220.00	0.00257
11405 Communications Admin. Building	0.532	$210.00	0.00253
34042 Reserve Forces Training Facility	0.500	$541.00	0.00092

It should be noted that the cost-value analysis ranks the alternatives in descending order of the value/cost ratio. Comparing Table 4.1 to Figure 4.1, the rank order of the alternatives changed significantly. For example, the TLFs are no longer the most preferred alternatives. This suggests that the buildings that are generating the best overall value are not necessarily the least expensive alternatives. It should also be noted that difference between the most and least expensive contracts is extensive. Furthermore, the value/cost analysis, with a few exceptions, ranks the alternatives from the least expensive to the most expensive. This suggests that the usefulness of this table and the value per dollar analysis is limited.

Step 9: Sensitivity Analysis

The purpose of this step is to examine how sensitive the results are to changes in the hierarchy weights (Kirkwood, 1997). The weight of a single value is varied, while the weights of the remaining values remain proportional. The sum of the values in each tier will still sum to 1. A graph is generated that shows how the alternative ranking will change with respect to variation in this value. This is useful for several reasons. First, the decision makers may have made errors in estimating or communicating their weights in the hierarchy. Second, external changes, such as a sharp increase in tipping fees, can change the weights of the hierarchy. Rather than having to perform the entire analysis again, sensitivity analysis lets the decision maker see how a different weight would change the results.

There are two basic methods of examining the sensitivity of the alternatives to changes in the weights of the value or measures. The first is a global sensitivity analysis,

where the weight of the value or measure of interest is varied while all of the other weights in the hierarchy vary proportionally. The second is a local sensitivity analysis, where the weight of the value or measure of interest is varied, while all of the weights of the values in the same tier of the hierarchy vary proportionally.

Based on the data collected for the buildings that have been identified for removal at Wright Patterson Air Force Base, some measures and values will be less sensitive than others. The measures that were identified earlier in this chapter as the same or similar across all alternatives should not be as sensitive to changes in the weight as other measures. The significant findings of the sensitivity analysis are explained below.

Figure 4.2 shows the global sensitivity analysis for the top tier value Simplicity. This graph shows that for the weights immediately surrounding the current weight, the top alternatives remain the same. Therefore, in this range, the alternatives are not very sensitive to the changes in weight. It is only for the lower weights that the top alternatives change. If Simplicity becomes less important to the decision makers, alternatives that do poorly in Simplicity but well in the other measures may become more preferred. Another important factor to notice is the fact that as the weight increases the value of the alternatives that have minimal parking lot space and concrete construction drop. This is because their score will drop as Simplicity becomes more and more important.

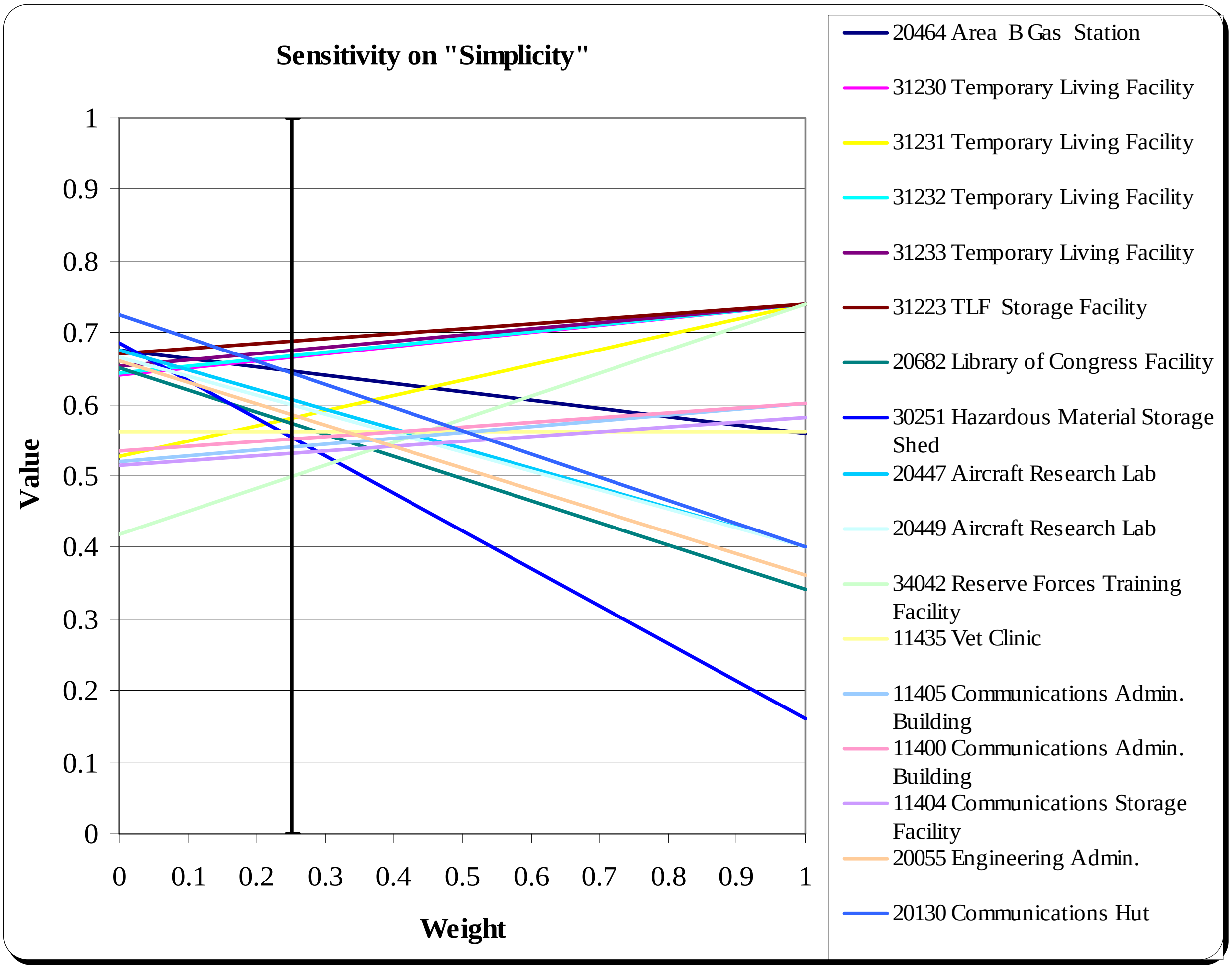


Figure 4.2. Sensitivity on Simplicity

The sensitivity analysis for mission impact, shown in Figure 4.3, shows some variation in the top alternatives as the weight is varied. However, the Reserve Forces Training Facility drops dramatically in value as the weight for mission impact increases. These facilities are the largest buildings on the alternatives list with respect to square footage, so they will take the most time to deconstruct. Furthermore, the Reserve Forces Training facility was identified for removal to support C-5 operations on the base, so the

need for the building site is more important than the need for the other building sites. On the other hand, its large size means that a higher volume of waste can be diverted, so the potential for minimizing the environmental impact is also greater. This alternative also has extensive parking lot space as well as mixed composition. Therefore, as the weight for Mission Impact decreases, the model will favor alternatives that are not as preferred in terms of Mission Impact, but do well in other measures. As the weight for Mission Impact increases, the fact that the Reserve Forces Training facility will take so long to deconstruct, coupled with the fact that there is an urgent need for the building site, makes deconstruction of this building less desirable.

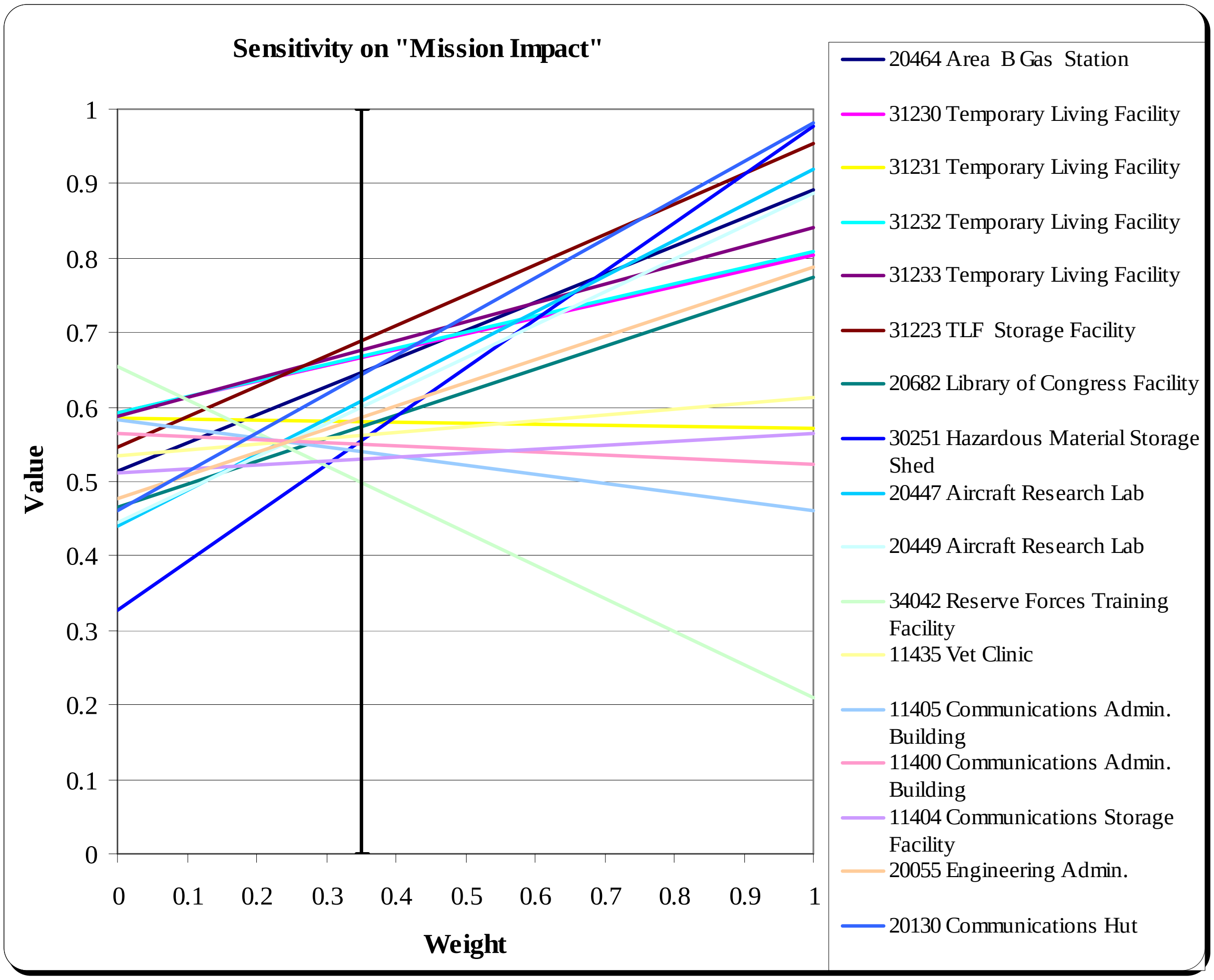


Figure 4.3. Sensitivity on Mission Impact

Figure 4.4 shows the sensitivity of the Potential for Cost Avoidance value. The measures under Potential for Cost Avoidance do not vary significantly among the alternatives, so the ranking of the alternatives does not vary significantly with respect to the weight. For this value, as the weight goes up, the model will favor older alternatives and newer construction will be less desirable options for deconstruction. The TLFs

remain top alternatives until the weight reaches 0.7 when the older facilities are the highest ranking.

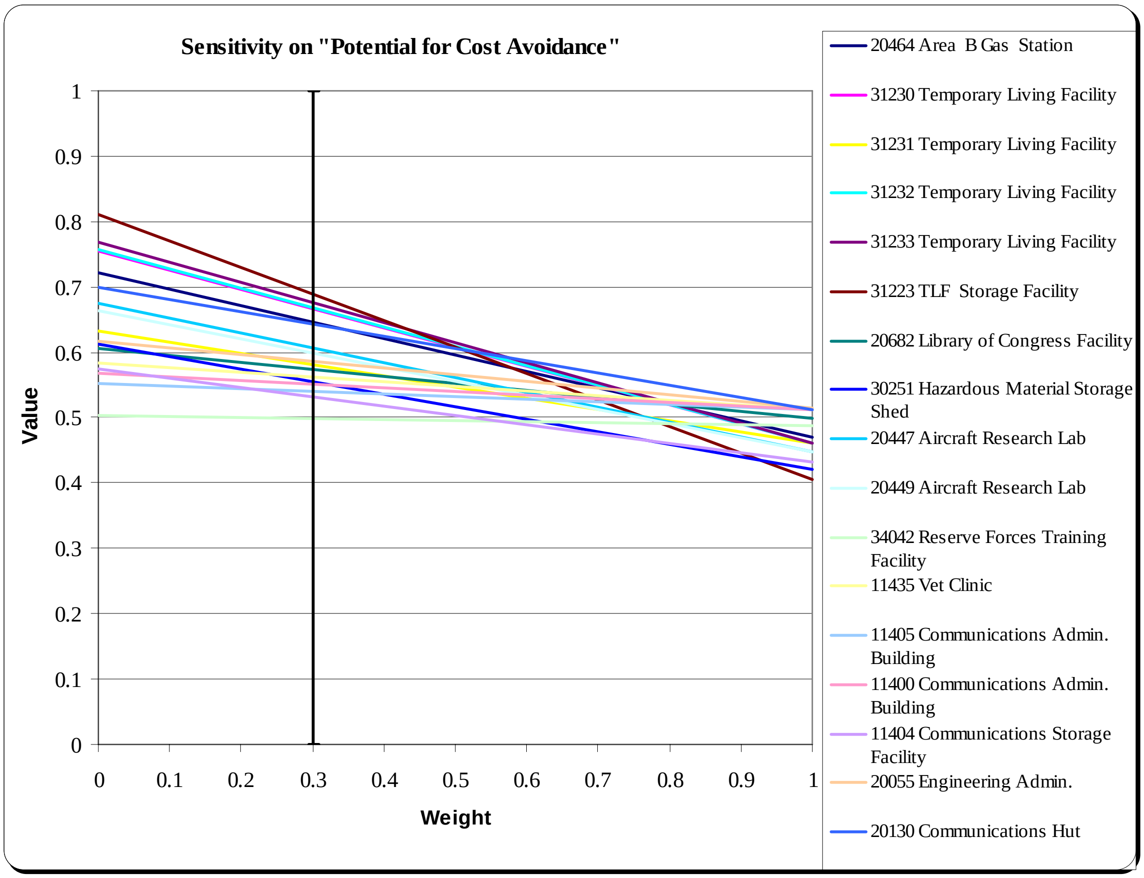


Figure 4.4. Sensitivity on Potential for Cost Avoidance

The sensitivity analysis for Environmental Impact is shown in Figure 4.5. Because the alternatives were set at an 80% diversion rate, the measure that varies under Environmental Impact is the Waste Diverted. This measure favors larger structures,

because an 80% diversion rate diverted more debris for a larger building. In the feasible range of weights immediately surrounding the current weight, the TLFs continue to dominate. As the weight increases, the largest structure, the Reserve Forces Training Facility, dominates the other alternatives.

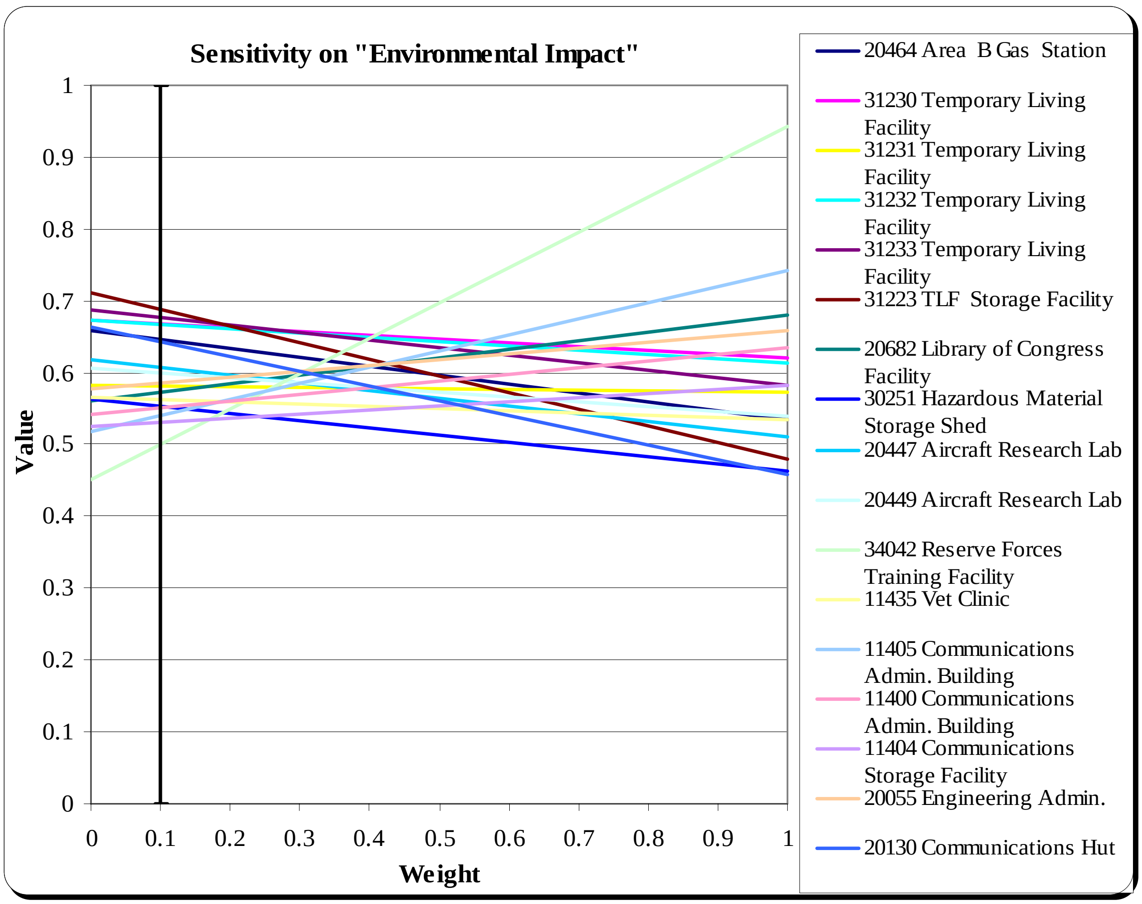


Figure 4.5. Sensitivity on Environmental Impact

The sensitivity analysis for select values are shown and explained below. The sensitivity analysis for these values was chosen because they either demonstrate sensitivity to the changes in weights or demonstrate some important aspect of the model. The global sensitivity analysis graphs for the other values are provided in Appendix B, as well as the global analysis for the values.

Figure 4.6 shows the sensitivity for the accessibility or the parking lot space available to each structure. For the range immediately surrounding the current weight, the top alternatives are not sensitive; however, if the weight doubles from 0.1 to 0.2, then the ranking of the alternatives starts to change. The values for the buildings converge into three separate areas. First, the most accessible buildings, those with extensive parking lot space, increase dramatically in value as the weight increases and converge at a value of 1. The buildings with moderate parking lot space converge at a value of 0.6 and the buildings with minimal parking lot space converge at a value of 0. This graph shows that the alternatives are very sensitive to increases in weight for accessibility.

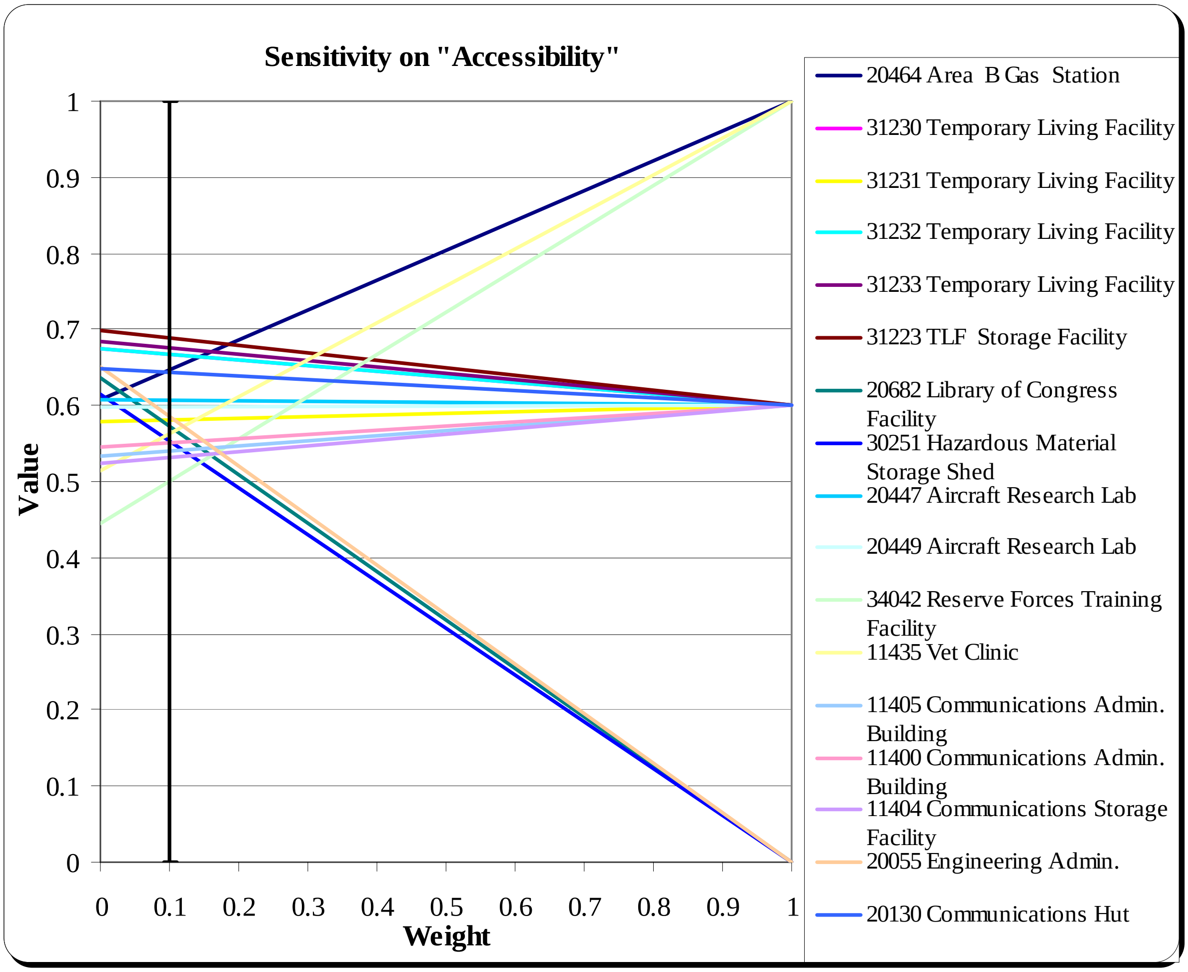


Figure 4.6. Sensitivity on Accessibility

Figure 4.7 shows the sensitivity of Time to Complete. As the weight for Time to Complete increases, the smaller building structures are favored. Recall that the method used to determine the completion time for deconstruction was estimated based on the square footage of the building. These smaller structures are favored as the weight for this value goes up, while the preference for larger facilities decreases. Notice that the

Reserve Forces Training facility will have a value of 0 if the Time to Complete were the only criteria for the decision makers. This graph appears to demonstrate a significant amount of sensitivity of the alternatives to changes in the weight, but for weights higher than the current weight, the top alternative is either the Communications Hut or the TLF storage facility. The changes in the top alternative change the most in the range around the current weight. This suggests that extra care should be taken in ensuring that the value function for this measure accurately represents the decision maker's preference.

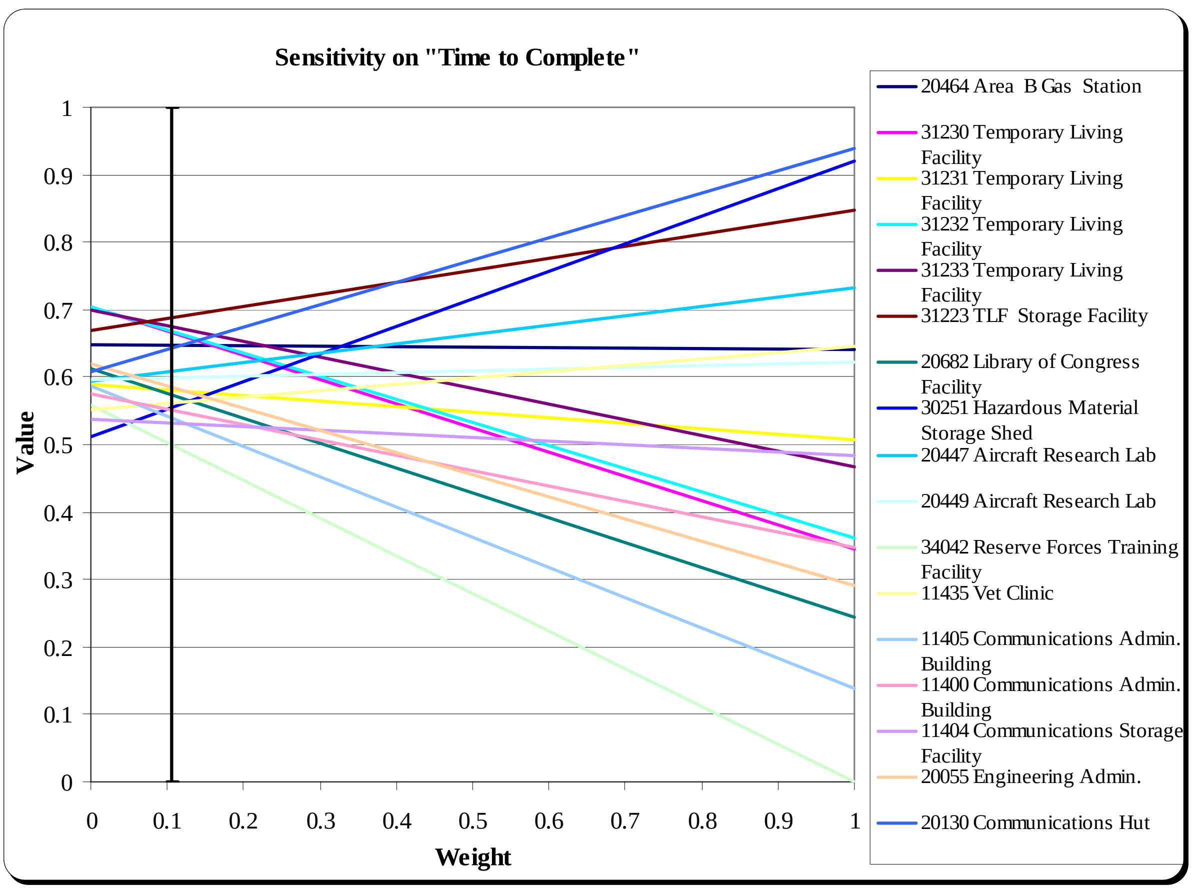


Figure 4.7. Sensitivity on Time to Complete

The sensitivity analysis in Figure 4.8 shows behavior that is similar to the sensitivity analysis for accessibility. As the weight increases, the alternatives converge into three separate areas. The alternatives with increasing values over the range of the weight are the buildings that have been identified as having no need for the site. The alternatives converging to a value of 0.6 are the ones that have been identified as having a Non-Urgent Need. Finally, the Federal Reserve Training Facility becomes much less desirable as the weight increases because of its urgent need.

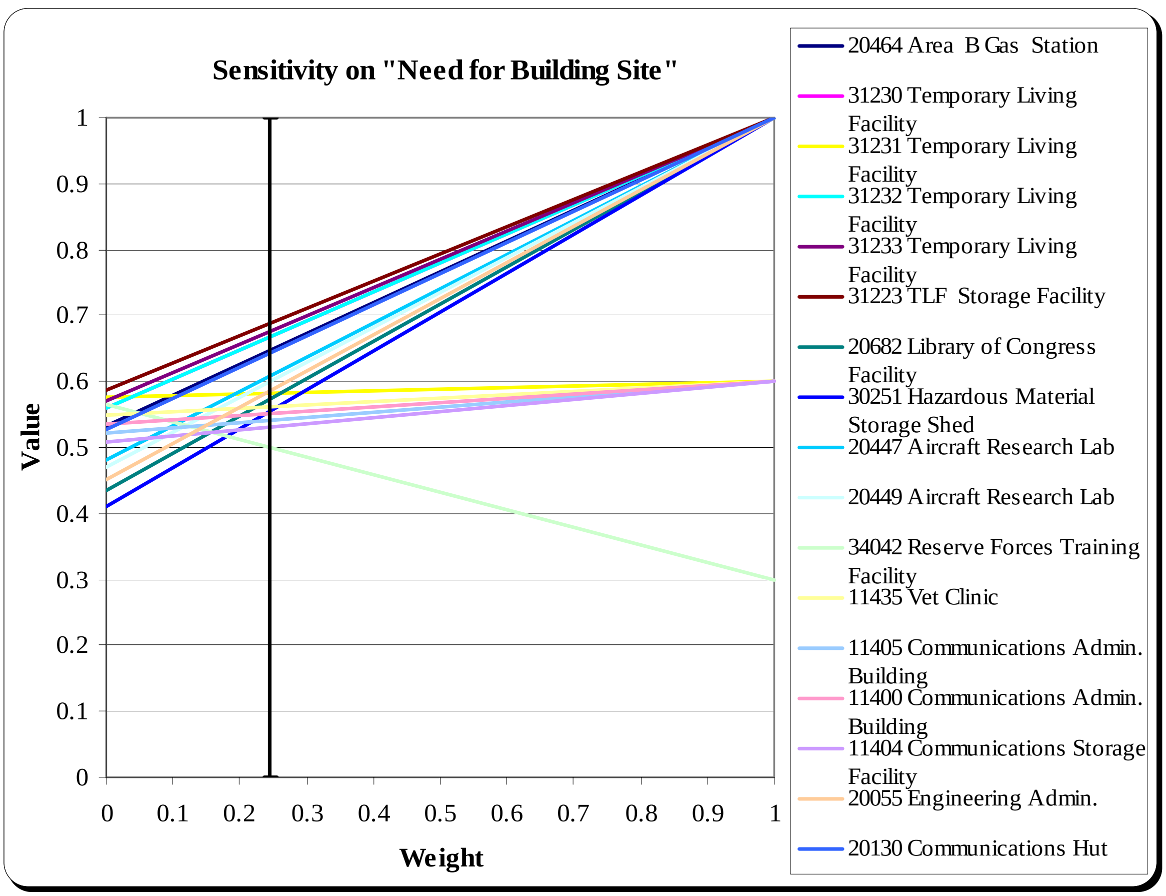


Figure 4.8. Sensitivity on Need for Building Site

The final sensitivity graph is shown in Figure 4.9. In the range surrounding the current weight, the top alternatives are still the TLFs. After a weight of approximately 0.25, the Federal Reserve Forces Training facility dominates all other alternatives for the remainder of the weights. The reason for this is the size of the facility. As stated before, larger facilities offer the chance to divert a higher volume of waste. The Federal Reserve Forces training facility has tens of thousands of square feet of mixed construction. Therefore, as the weight for the Waste Diverted increases, this facility is the most desired option.

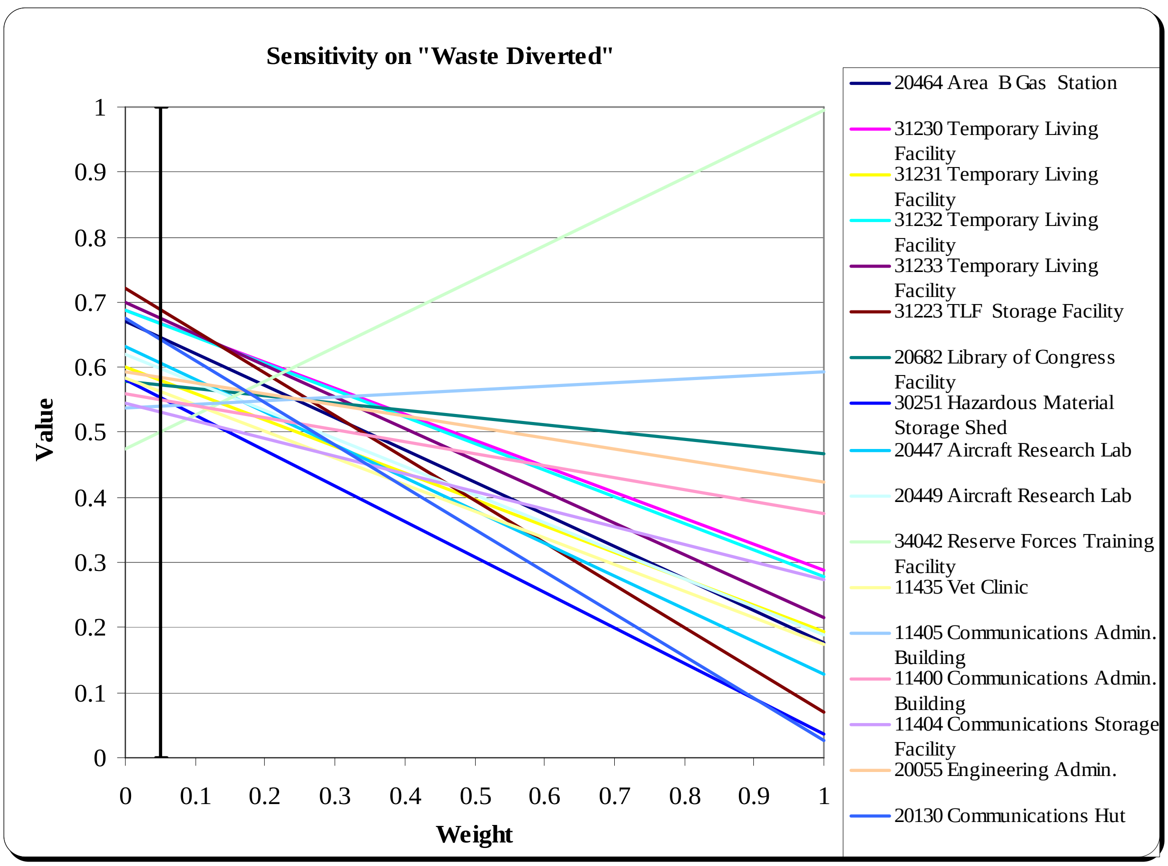


Figure 4.9. Sensitivity on Waste Diverted

Chapter 5. Findings and Conclusions

Introduction

The purpose of this chapter is to summarize the findings of this research effort and state the conclusions that have resulted from this analysis. The applicability of value focused thinking to building deconstruction, the strength and weaknesses of the model, uses and implications of the model, and recommendations for future research are addressed in this chapter.

Value Focused Thinking and Building Deconstruction

This thesis demonstrates that the Value Focused Thinking decision analysis method is a useful tool for the United States Air Force and for Wright Patterson Air Force Base to examine deconstruction as a removal option for buildings. First, it provides a method for identifying and organizing the base's values concerning building removal. Second, it serves as a method for identifying which buildings will be the best candidates for deconstruction. Deconstruction is a sustainable and environmentally sound building removal option, but the Air Force and Wright Patterson Air Force Base must deal with a number of conflicting factors.

Strengths and Weaknesses of the Model

There are various strengths of the decision making model presented in this thesis. First, it promotes value-based decision making. By forcing decision makers to identify and document their values, decisions that fulfill those values can be identified and

implemented. Second, this value focused thinking model provides an objective method for evaluating alternatives. Data is collected and analyzed for each alternative and the output of the model represents the best alternative. If the hierarchy truly reflects the decision maker's values and the data is correct, the top ranked alternative is considered the best option. The model is also flexible since the decision makers can apply the model to buildings on other military installations. If the values are the same, then the weights can be modified relatively easily; alternatively, the sensitivity analysis can be used to examine the differences in the weights. Finally, the operability of the model is also considered an advantage. The data is easily understood and the information should be available for all of the buildings on any military installation. All of the factors discussed above add to the strength of the decision analysis model presented in this thesis. If the decision makers values are different, the methodology demonstrated in this research can be applied to varying sites to develop new models.

Conversely, there are two weaknesses that may hinder the accuracy of the value focused thinking model. First, while sensitivity analysis is performed concerning the decision maker's weighting of the values, no other accuracy check exists for any other aspect of the model. There is essentially no method for ensuring that the value functions accurately and completely reflect the decision maker's preference concerning a given measure. For some measures, it may be difficult to prove that the measure accurately reflects the attainment of the associated objective. These problems are inherent to any value focused thinking decision model, and the creator of the model simply has to trust that the decision maker accurately communicated their preferences.

The second weakness of the model lies in the data. For many measures, the scores for the alternatives are the same or very similar. For instance, the local tipping fee for each alternative will be the same and the distance to the local landfill will be similar for all buildings on Wright Patterson. The lack of variance among some of the data amplifies the importance of the scores for the other data. Essentially, a measure such as Time to Complete, where there was a lot of variance among alternatives, becomes more important to the overall ranking of alternatives. In the same way, the method that data was attained caused the model to favor smaller buildings. Since, larger buildings divert more waste; they also take more time to deconstruct which was one of the highest ranking measures. However, using square footage to calculate the expected time to complete deconstruction on a building causes the model to favor structures that are smaller.

Uses and Implications of the Model

The value focused thinking model that was constructed for this research can be used to analyze any group of buildings for their potential success in deconstruction. The model can be used in a similar manner at other military installations that have identified a group of buildings for removal and are considering deconstruction as a removal option. For many, the lack of experience with deconstruction can be a major deterrent, but this model can help decision makers identify which buildings will be the best candidates for a deconstruction project. Additionally, the nature of the model allows decision makers to realize what building characteristics are favorable for deconstruction.

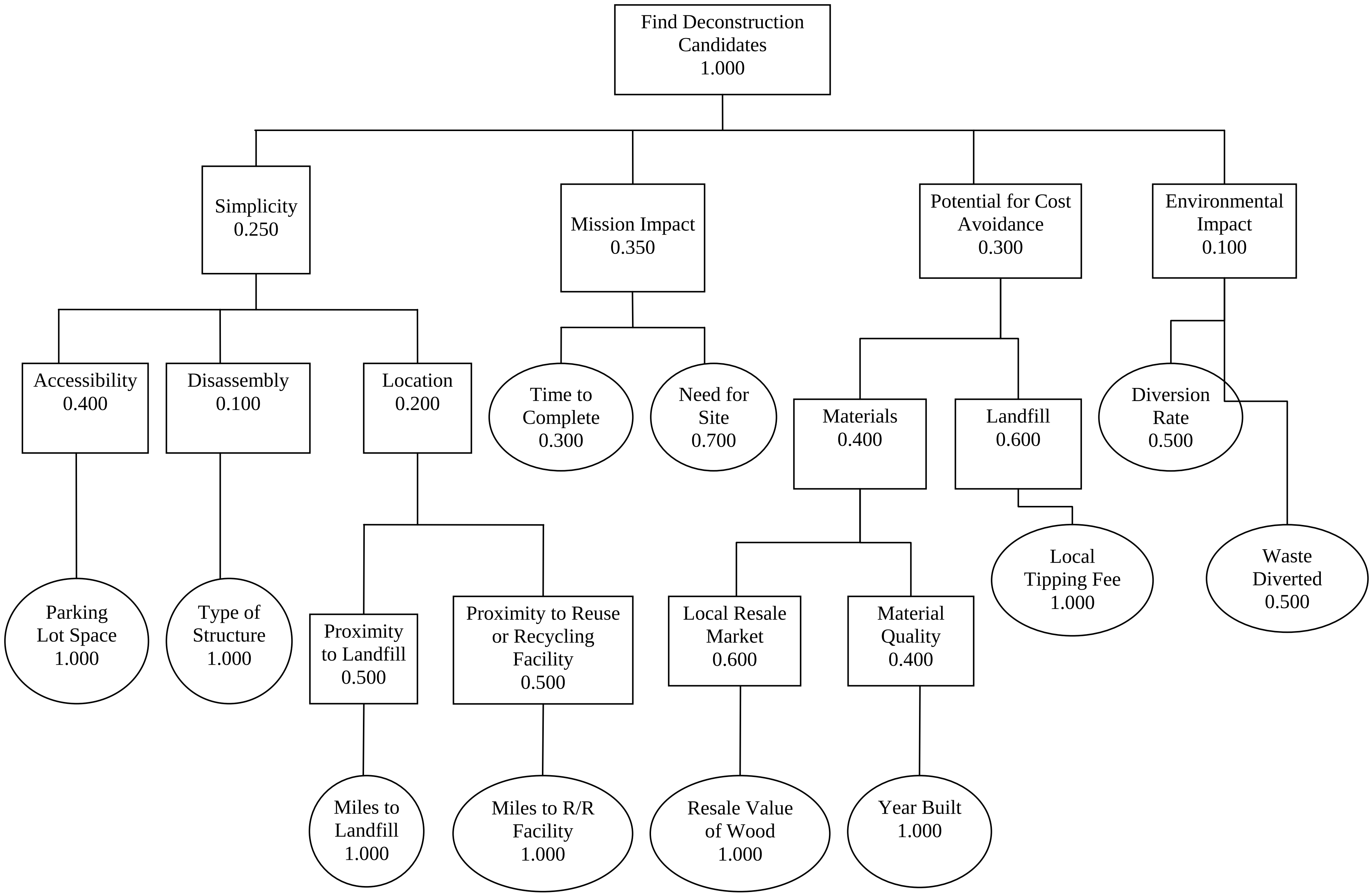
Recommendations for Future Research

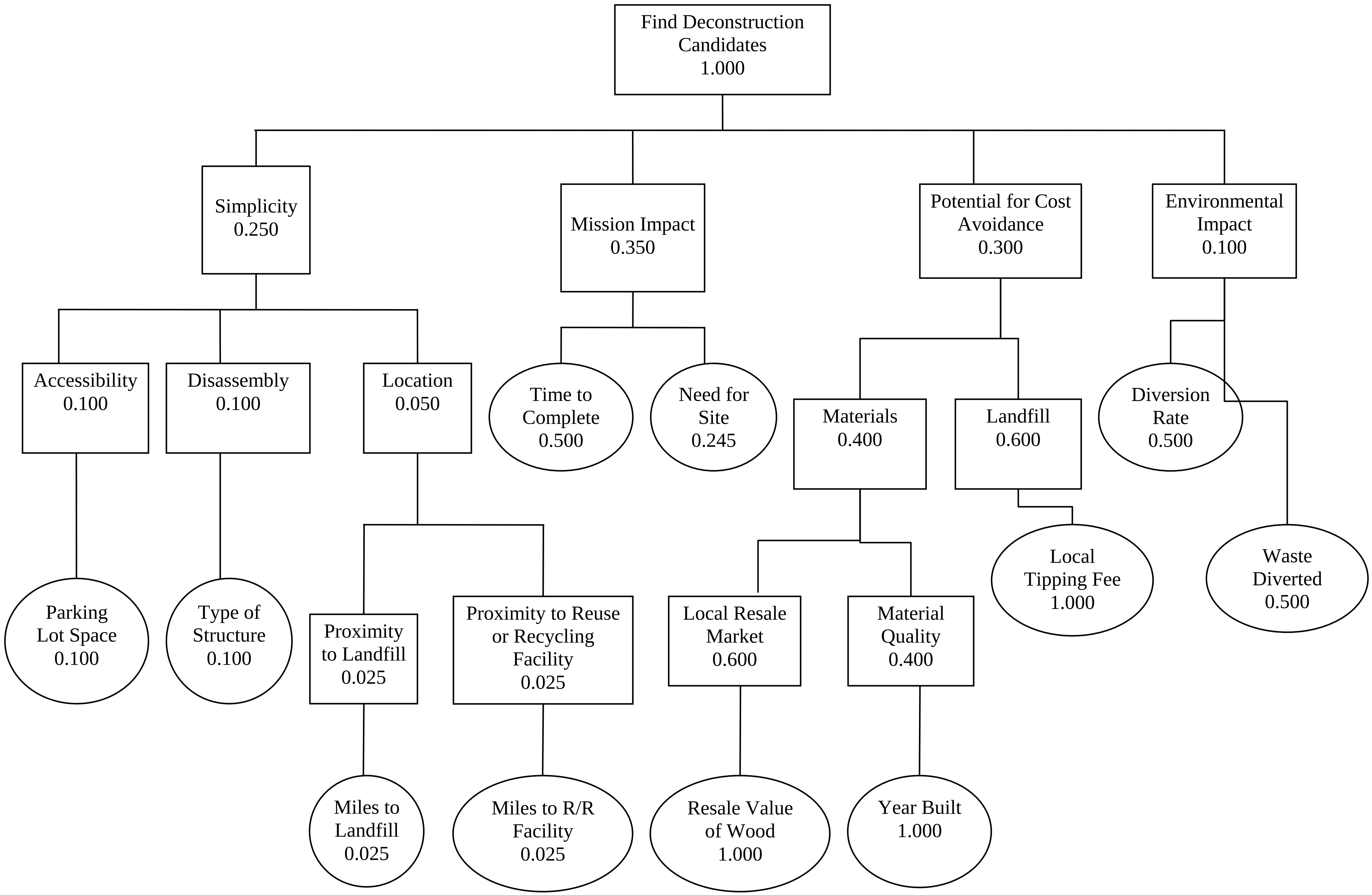
Certain aspects of the value model were generalized to promote simplicity. For example, determining the local resale value of wood was used as a proxy measure for the local resale market. More specific analysis of the materials composition of each building compared to the local materials market would add to the accuracy of the model and provide useful information on the economic potential of a building. In the same way, a method to examine the time to complete and the volume or weight of the resulting debris would increase the accuracy of the results. Furthermore, expanding the scope of the model to include the surrounding pavement, parking lots, and landscaping would further increase the accuracy of the decision model.

Conclusion

The Value Focused Thinking decision analysis methodology is a useful tool in examining the deconstruction of buildings on military installations. This research demonstrates how focusing on the values of the decision maker can aid the identification of the best buildings for deconstruction. The model itself helps promote the reuse and recycling of building materials that result from demolition projects. It is recommended that the buildings that have been identified for removal at Wright Patterson be analyzed using this value focused thinking analysis model before a final removal decision is made.

Appendix A: Value Hierarchy




Find Deconstruction Candidates 1.000
Simplicity 0.250
Mission Impact 0.350
Potential for Cost Avoidance 0.300
Environmental Impact 0.100
Accessibility 0.100
Disassembly 0.100
Location 0.050
Time to Complete 0.500
Need for Site 0.245
Materials 0.400
Landfill 0.600
Diversion Rate 0.500
Parking Lot Space 0.100
Type of Structure 0.100
Proximity to Landfill 0.025
Proximity to Reuse or Recycling Facility 0.025
Local Resale Market 0.600
Material Quality 0.400
Local Tipping Fee 1.000
Waste Diverted 0.500
Miles to Landfill 0.025
Miles to R/R Facility 0.025
Resale Value of Wood 1.000
Year Built 1.000

Alternative	Parking Lot Space	Type of Structure	Miles to Landfill	Miles to Reuse or Recycling Facility	Time to Complete	Need for Site	Local Resale Value of Wood	Year Built	Local Tipping Fee	Diversion Rate	Waste Diverted
20464 Area B Gas Station	Extensive	Concrete	11.21	14.36	3.89	No Need	18	1970	28	80	144.832
31230 Temporary Living Facility	Moderate	Wood	13.51	17.02	9.29	No Need	18	1974	28	90	250.92
31231 Temporary Living Facility	Moderate	Wood	13.51	17.02	5.91	No Need	18	1974	28	90	159.66
31232 Temporary Living Facility	Moderate	Wood	13.51	17.02	8.85	No Need	18	1974	28	90	239.13
31233 Temporary Living Facility	Moderate	Wood	13.51	17.02	6.65	No Need	18	1974	28	90	179.64
31223 TLF Storage Facility	Moderate	Wood	13.51	17.02	1.445	No Need	18	1996	28	80	53.754
20682 Library of Congress Facility	Minimal	Mixed	12.77	13.2	12.27	No Need	18	1953	28	80	456.692
30251 Hazardous Material Storage Shed	Minimal	Concrete	12.68	16.62	0.72	No Need	18	1991	28	80	26.784
20447 Aircraft Research Lab	Moderate	Concrete	12.23	12.66	2.71	No Need	18	1980	28	80	101.06
20449 Aircraft Research Lab	Moderate	Concrete	12.23	12.66	4.13	No Need	18	1980	28	80	153.76
34042 Reserve Forces Training Facility	Extensive	Mixed	14.54	16.94	55.05	Urgent	18	1960	28	80	2047.98
11435 Vet Clinic	Extensive	Concrete	14.96	13.65	3.83	Non-Urgent	18	1944	28	80	142.53
11405 Comm. Admin. Building	Moderate	Brick	15.96	12.4	17.28	Non-Urgent	18	1944	28	80	643.06
11400 Comm. Admin. Building	Moderate	Brick	15.96	12.4	9.24	Non-Urgent	18	1944	28	80	343.85
11401 Communications Storage Facility	Moderate	Mixed	15.96	12.4	6.35	Non-Urgent	18	1987	28	80	236.406
20055 Engineering Admin. Building	Minimal	Brick	11.71	14.86	10.78	No Need	18	1942	28	80	401.202
20130 Communications Hut	Moderate	Concrete	11.81	12.23	0.54	No Need	18	1943	28	80	20.088

Appendix C: Sensitivity Analysis for Values and Measures

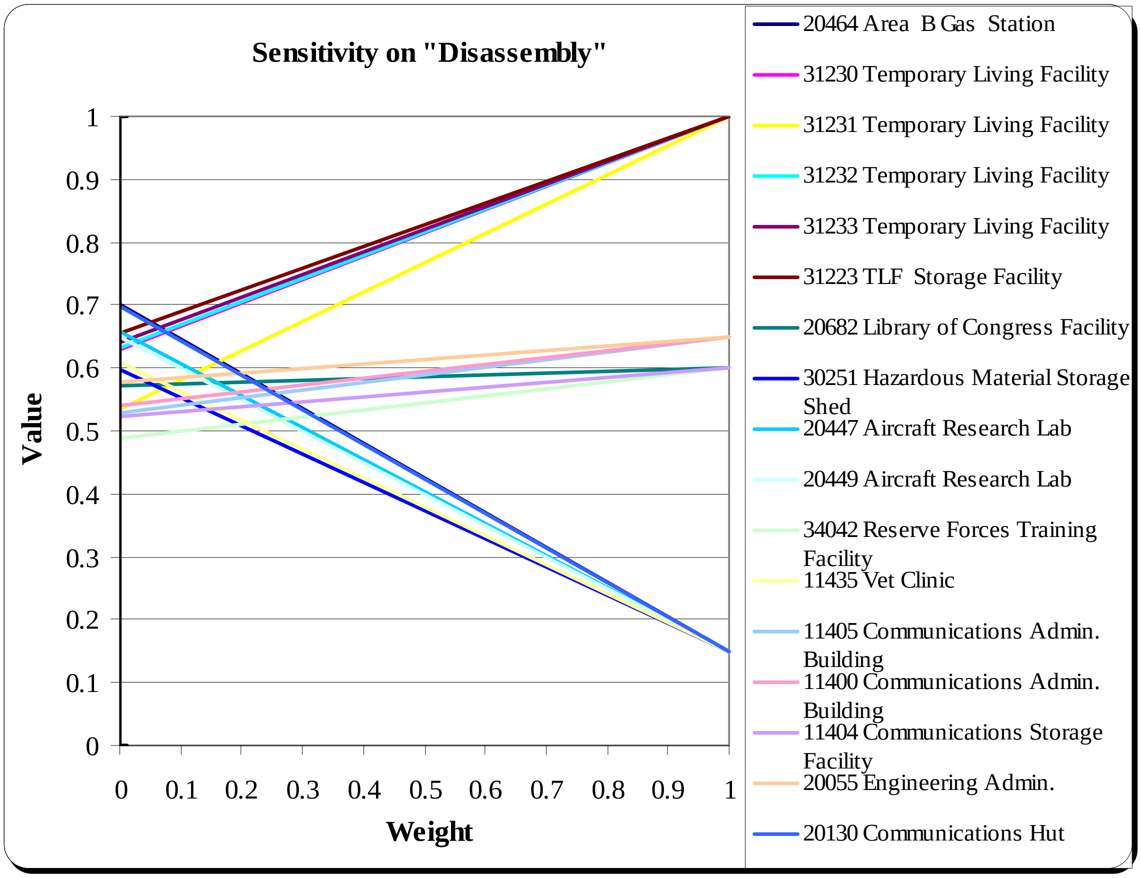


Figure C.1: Sensitivity on Disassembly

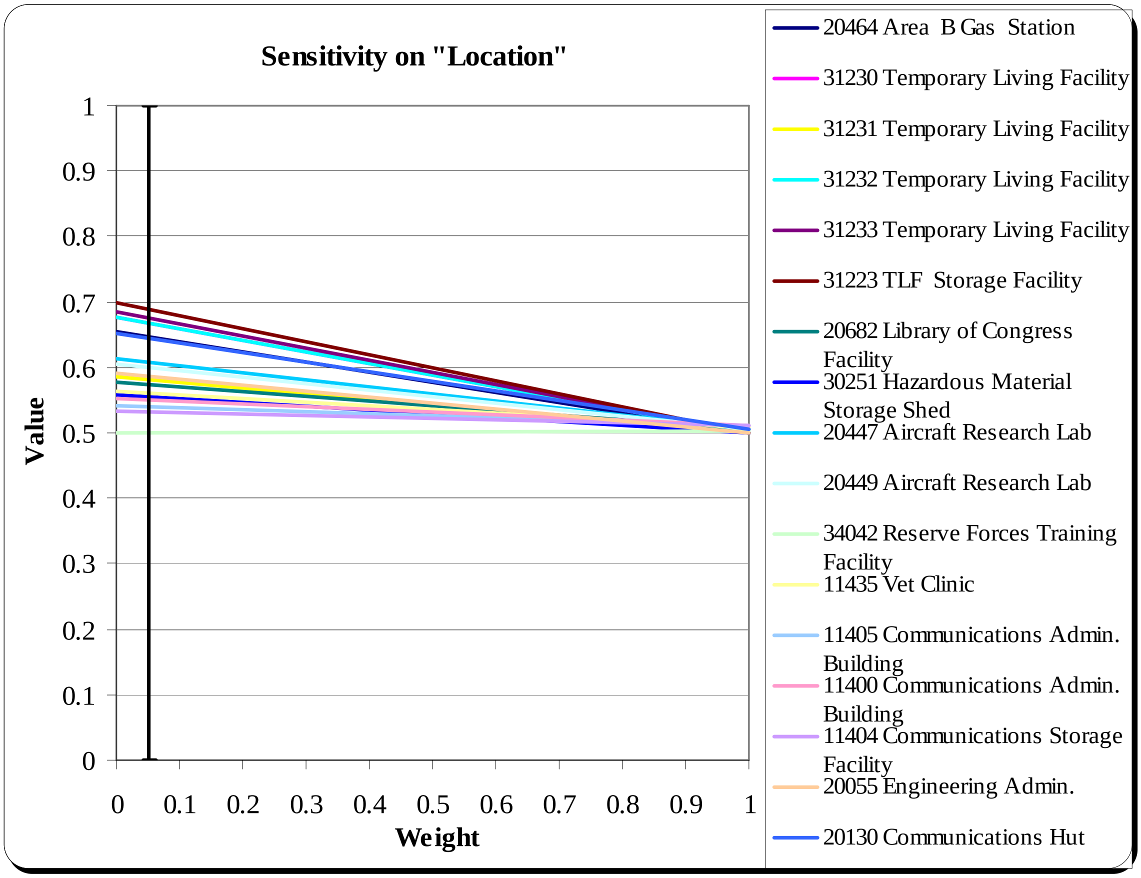


Figure C.2: Sensitivity on Location

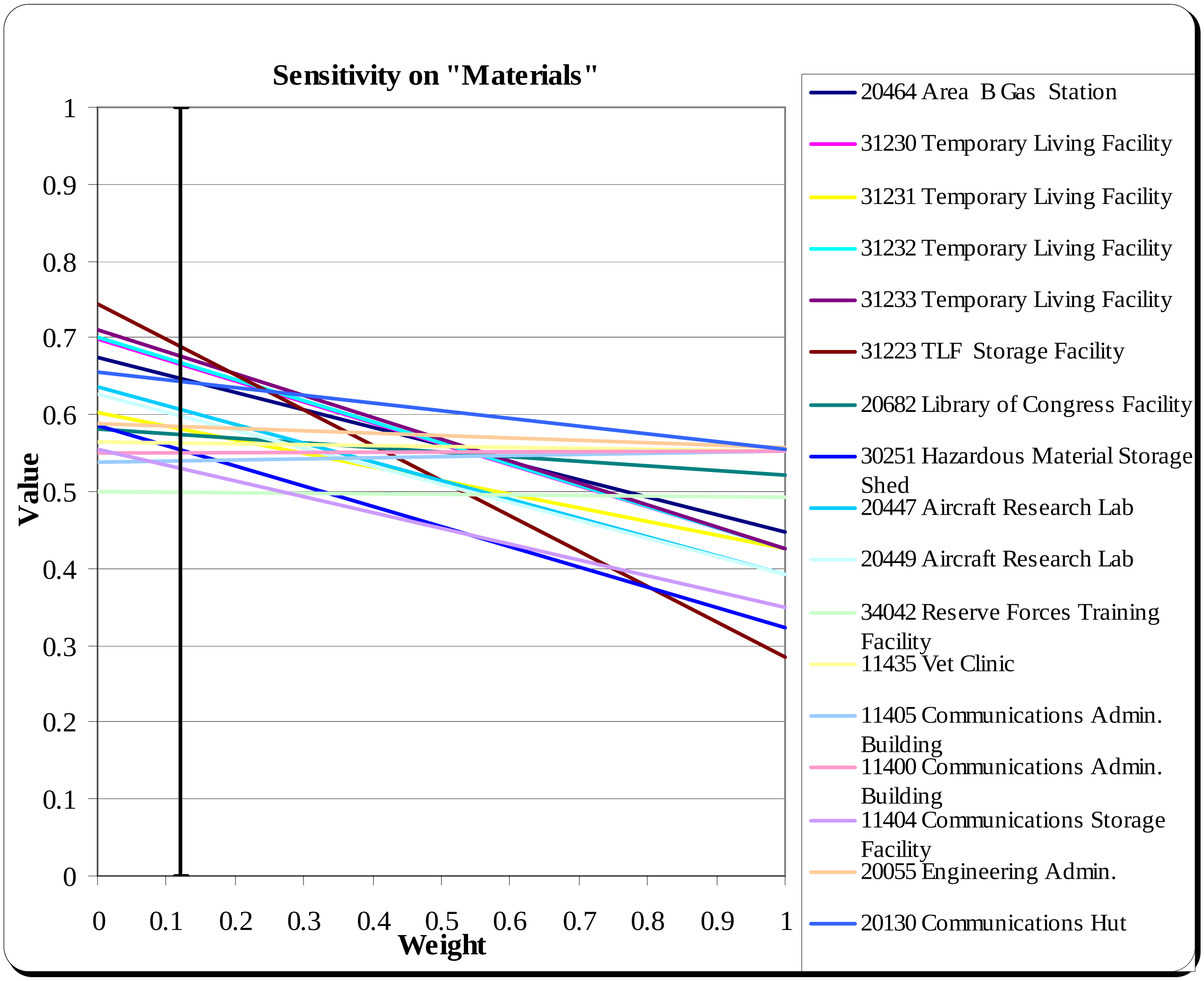


Figure C.3: Sensitivity on Materials

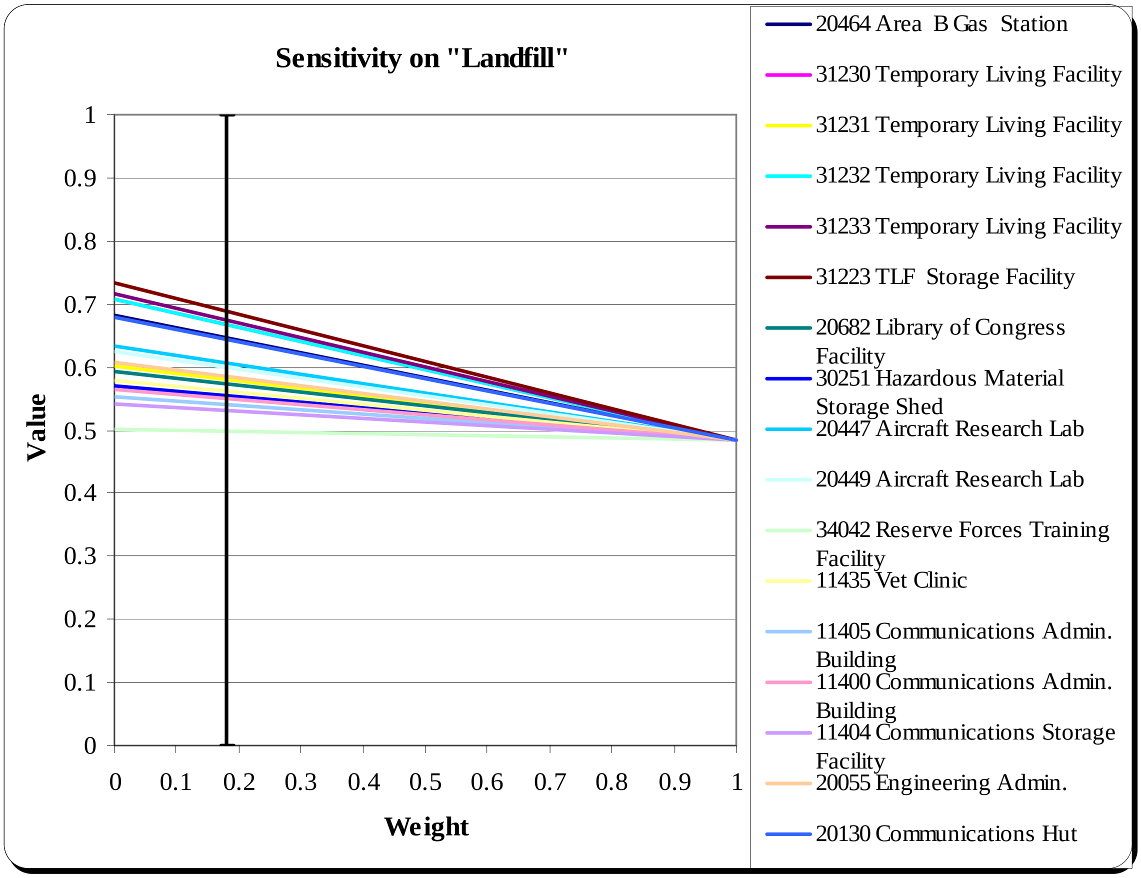


Figure C.4: Sensitivity on Landfill

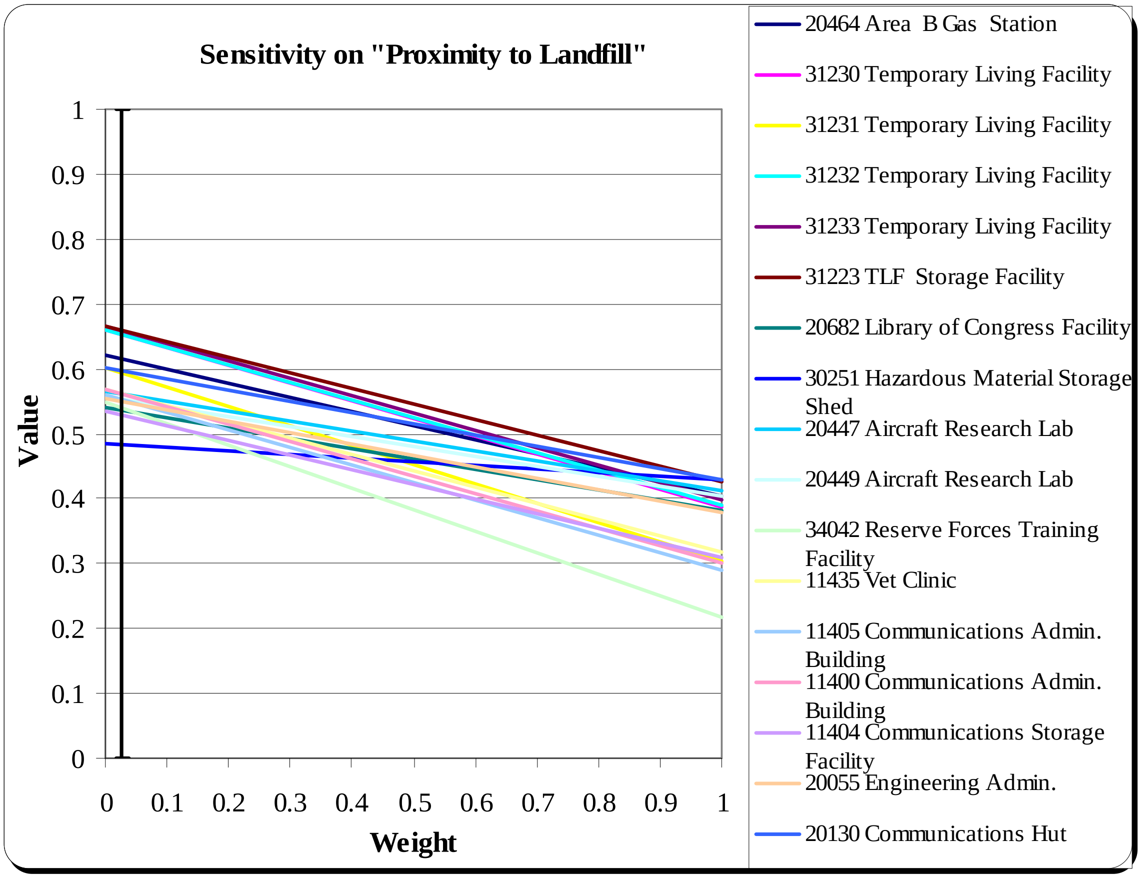


Figure C.5: Sensitivity on Proximity to Landfill

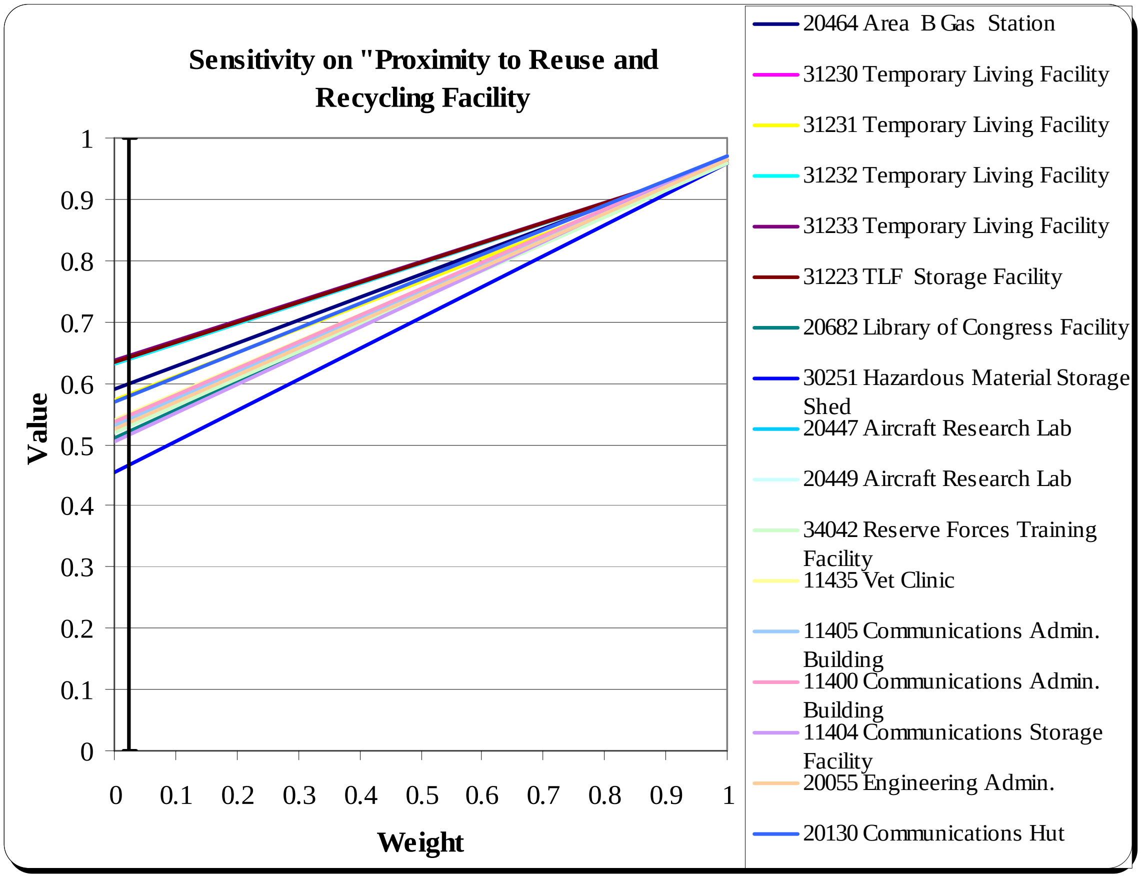


Figure C.6: Sensitivity on Proximity to Reuse and Recycling Facility

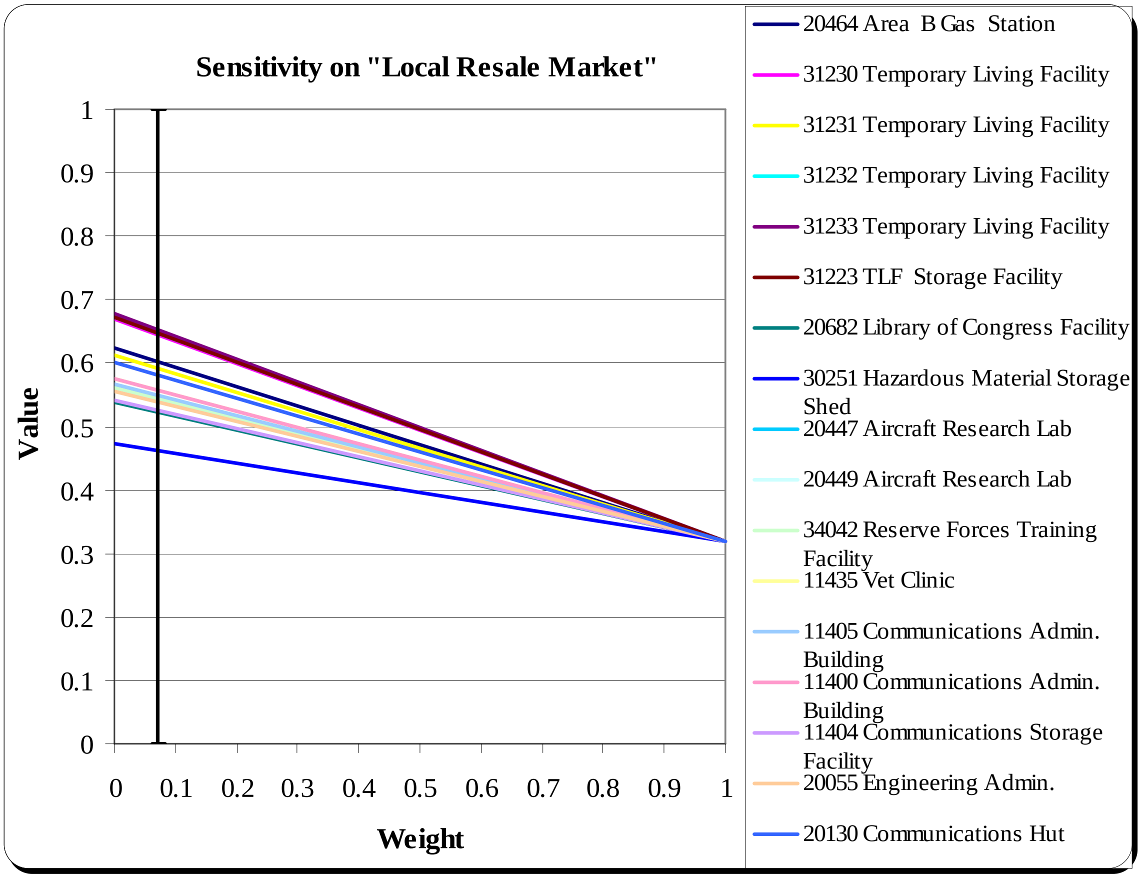


Figure C.7: Sensitivity on Local Resale Market

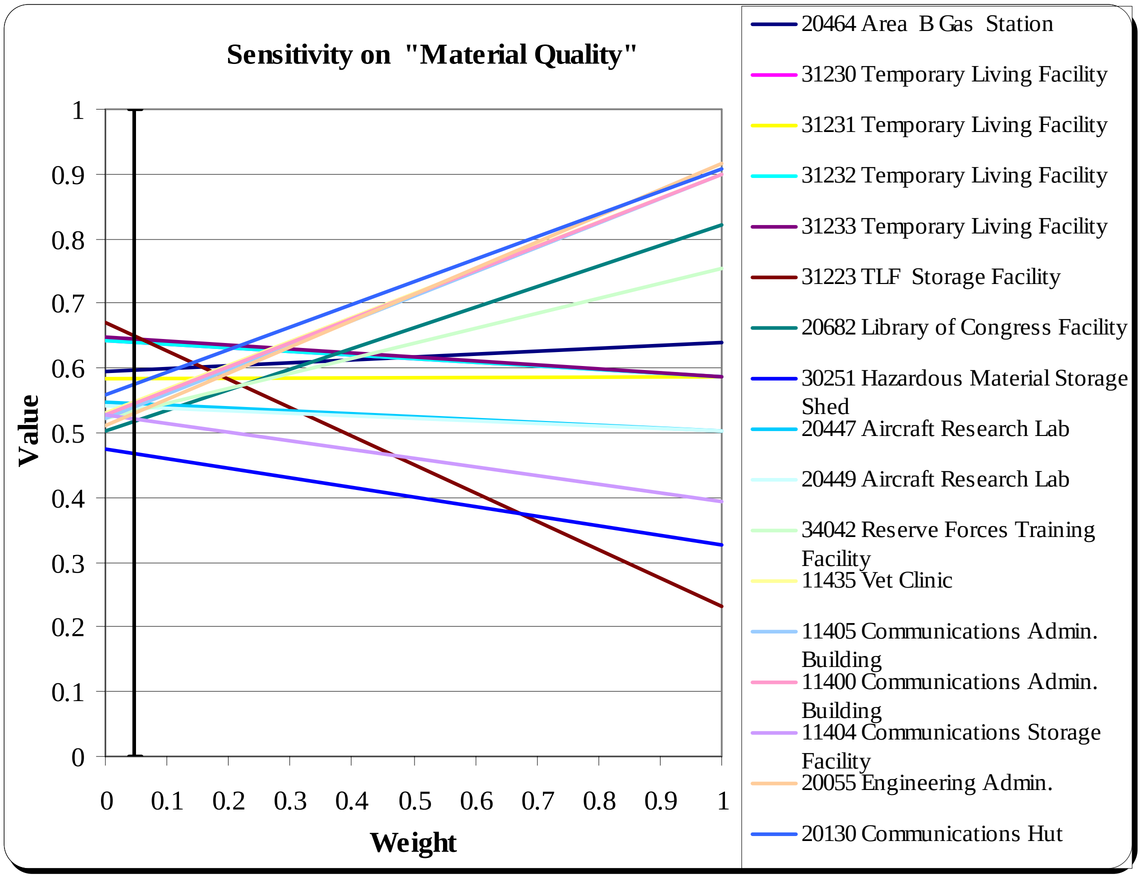


Figure C.8: Sensitivity on Material Quality

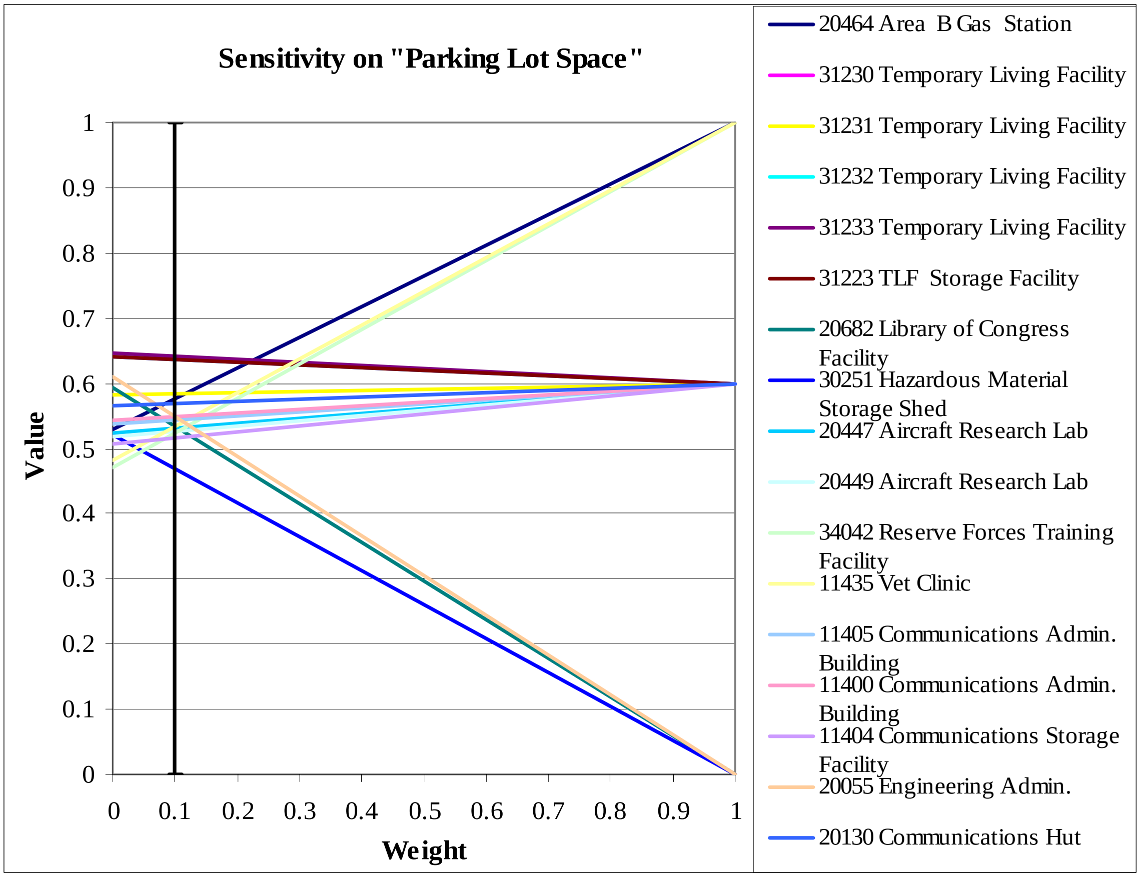
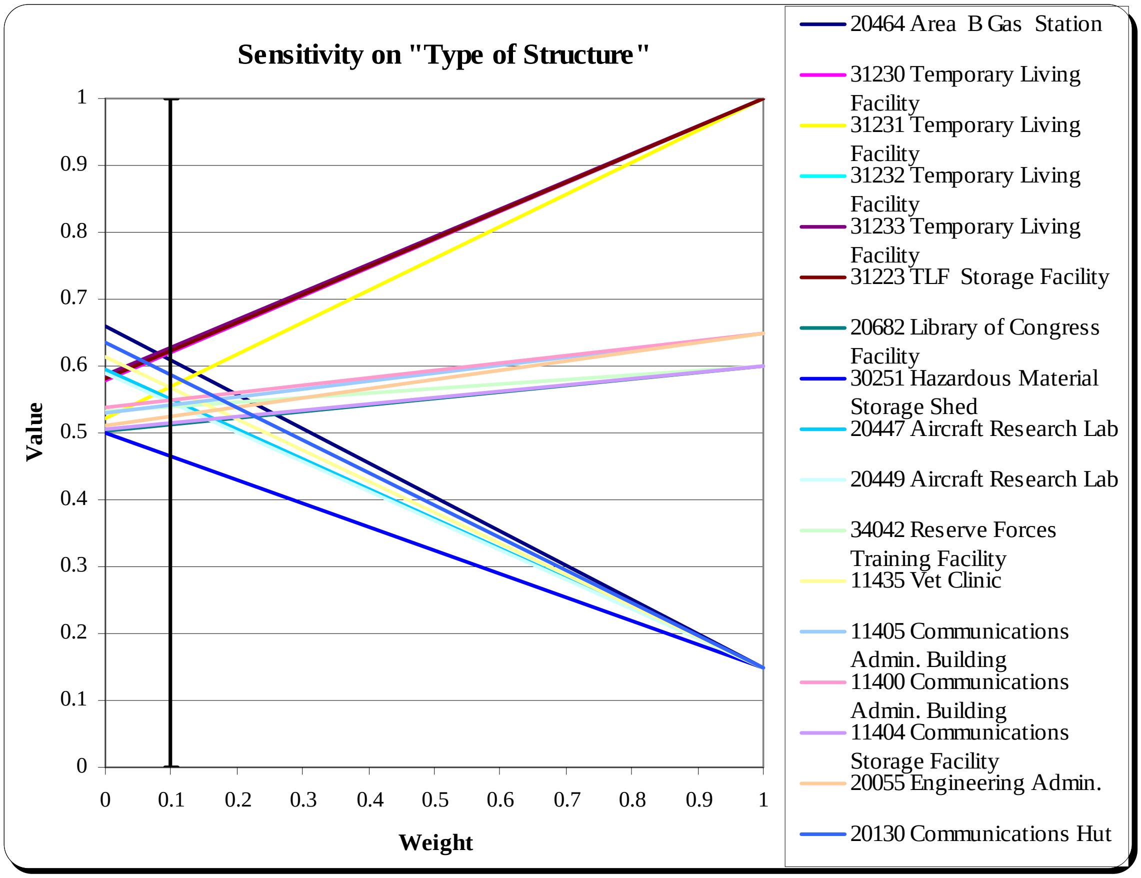


Figure C.9: Sensitivity on Parking Lot Space



C.10: Sensitivity on “Type of Structure”

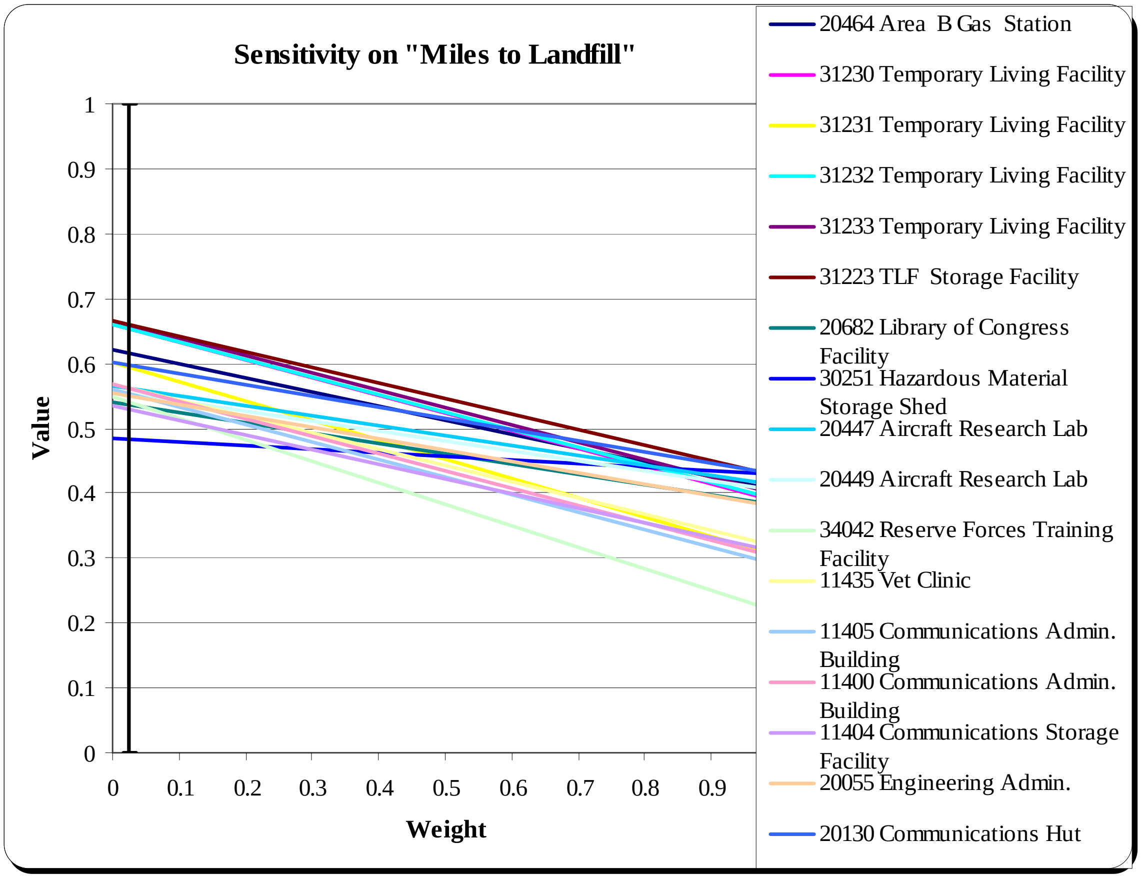


Figure C.11: Sensitivity on Miles to Landfill

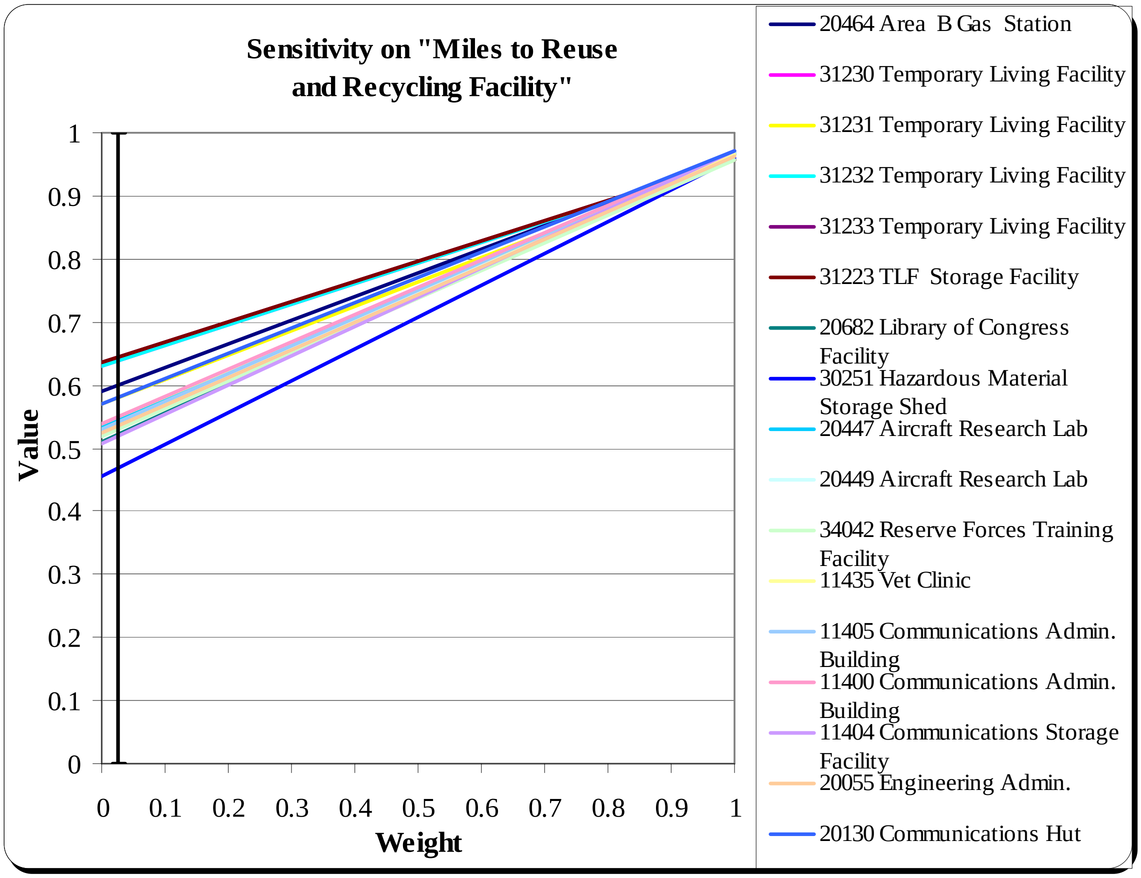


Figure C.12: Sensitivity on Miles to Reuse and Recycling Facility

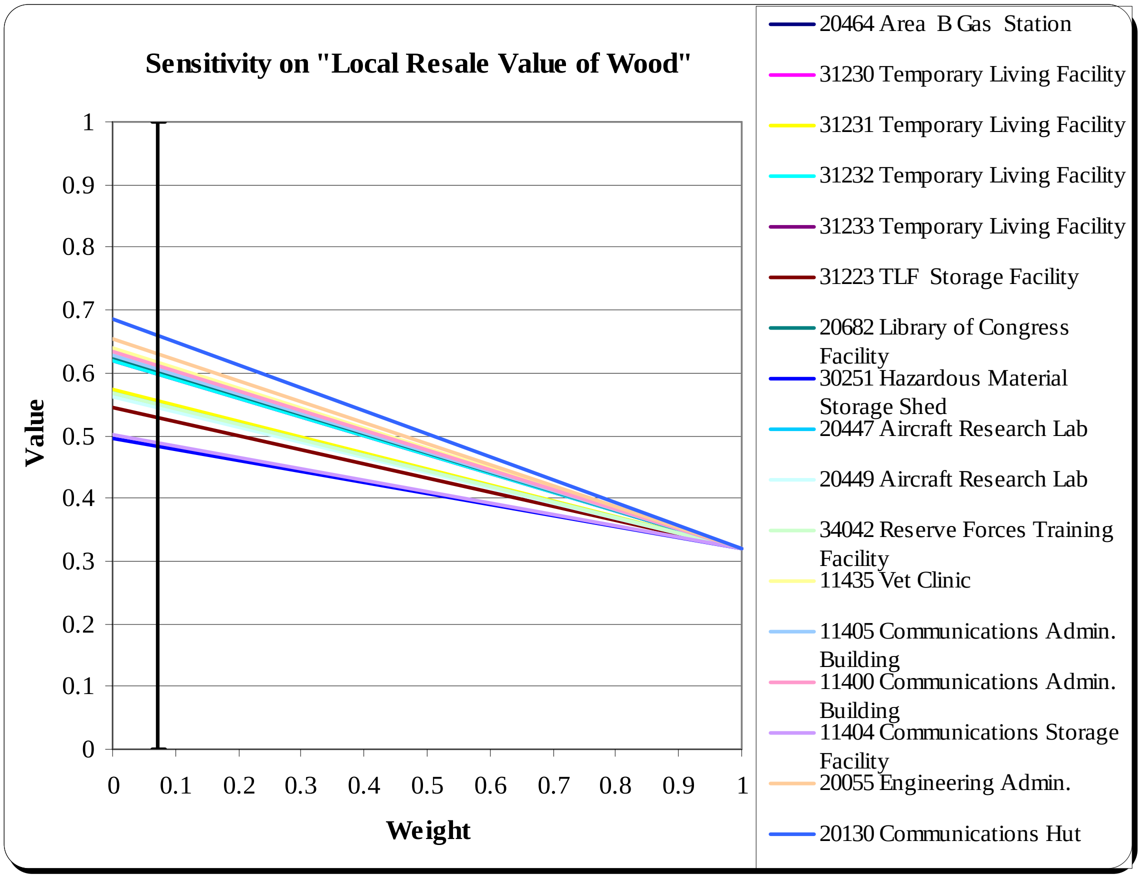


Figure C.13: Sensitivity on Local Resale Value of Wood

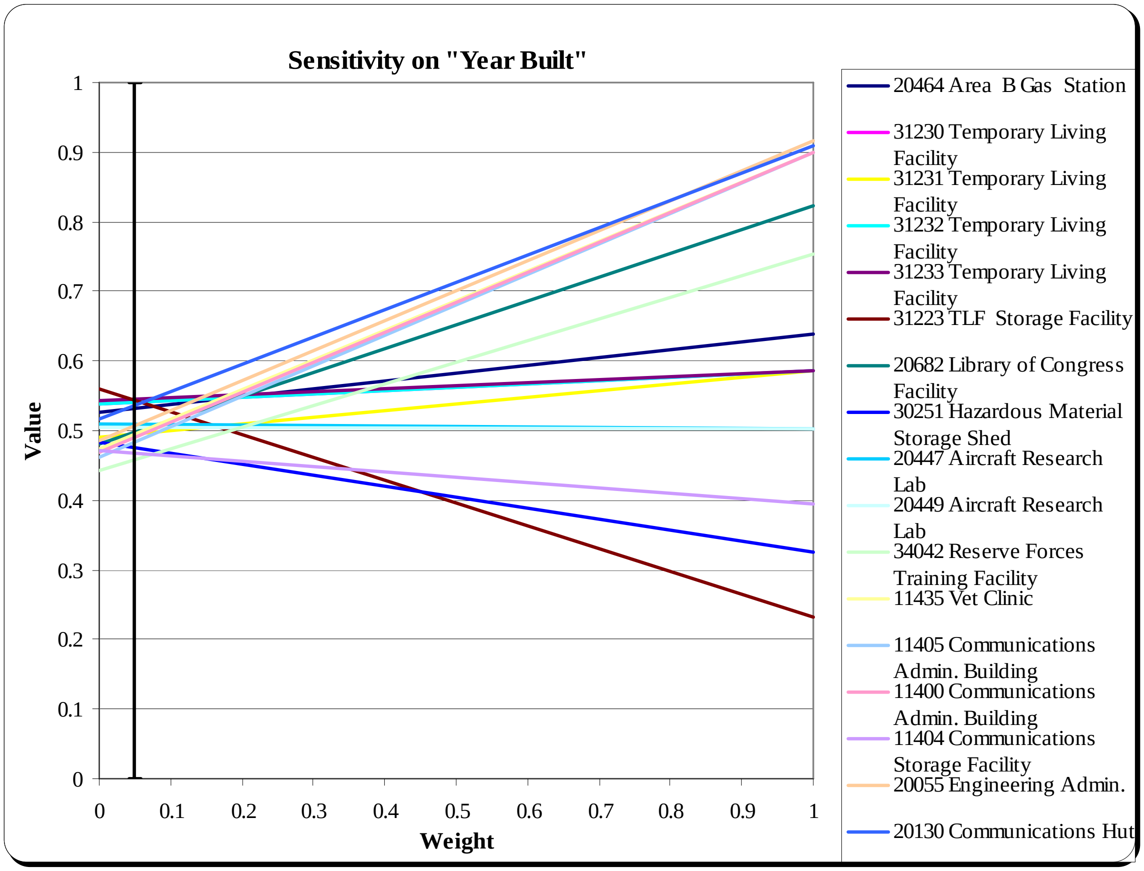


Figure C.14: Sensitivity on Year Built

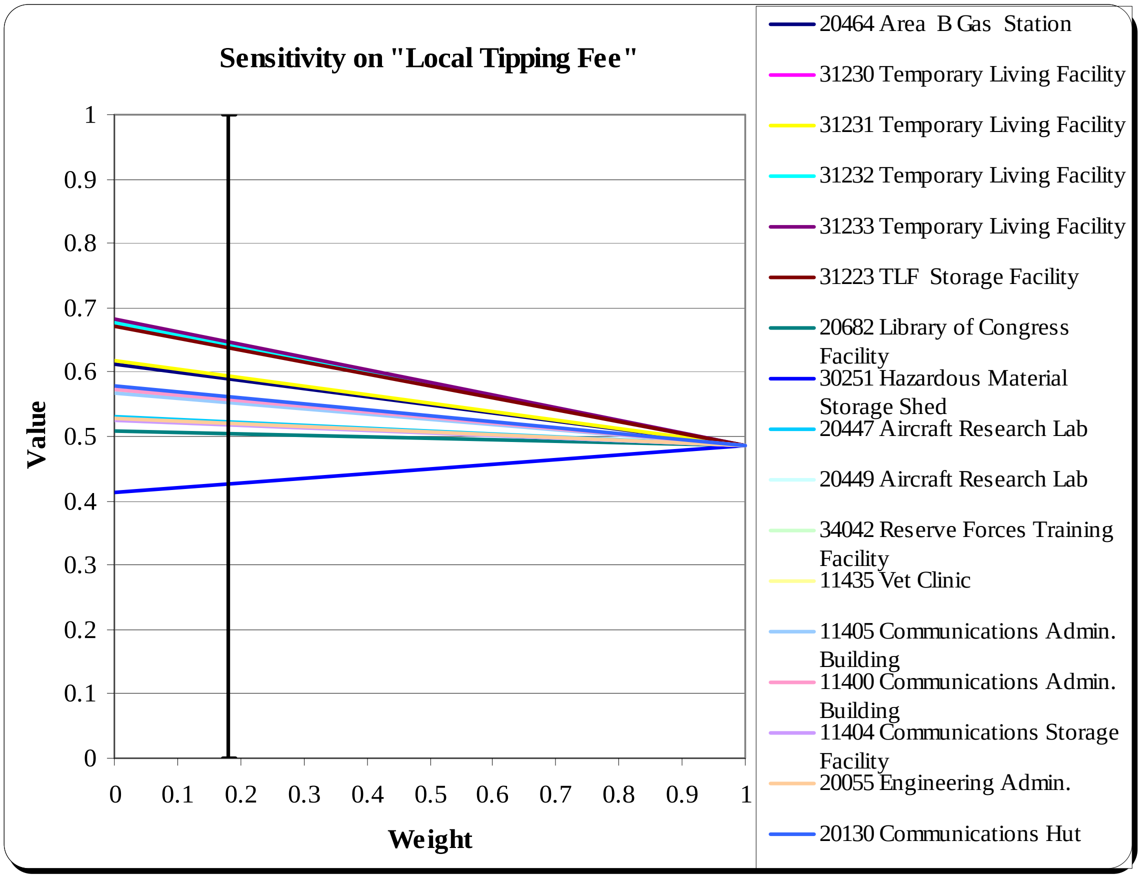


Figure C.15: Sensitivity on Local Tipping Fee

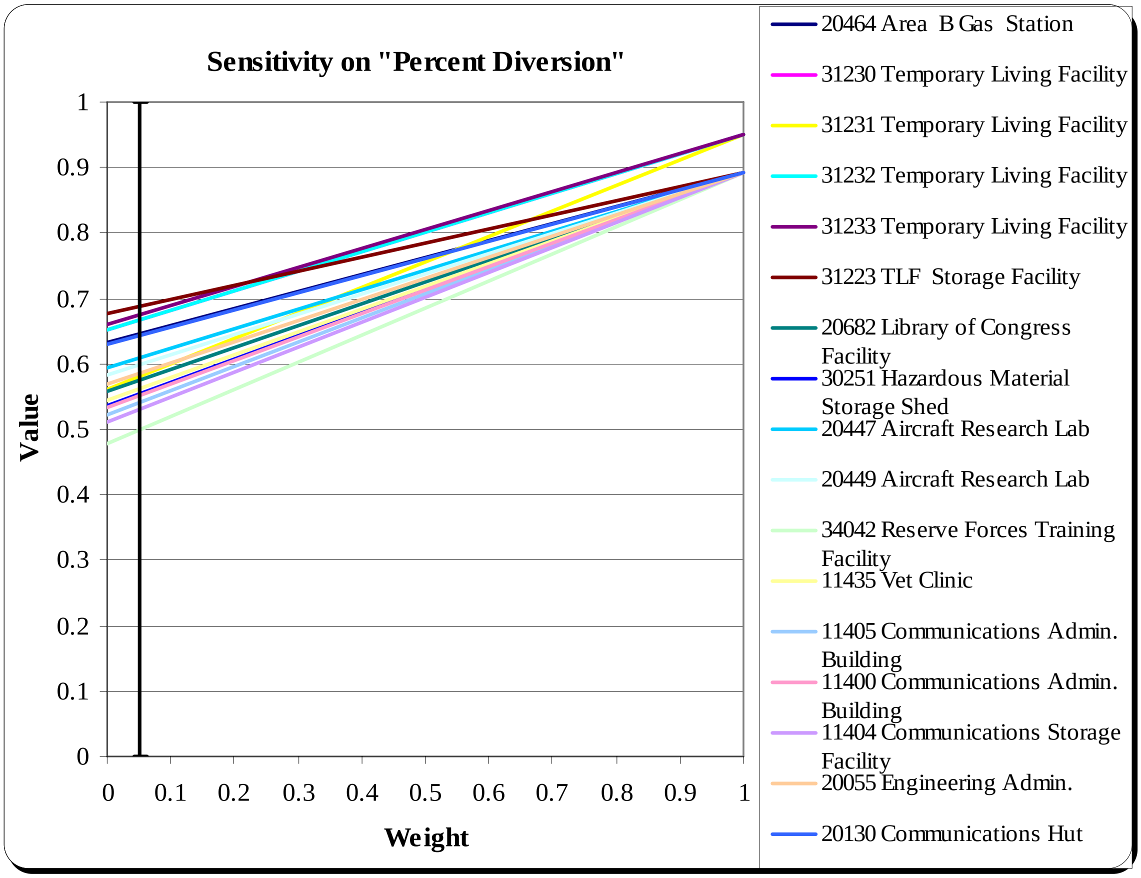


Figure C.16: Sensitivity on Percent Diversion

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14. ABSTRACT

The purpose of this research was to examine the reuse and recycling of building materials on Wright-Patterson Air Force Base. There are a variety of conflicting factors concerning the removal of a building and the model quantitatively evaluates alternatives with respect to the decision maker's values. The research questions were addressed with both a comprehensive literature review as well as the implementation of the value focused thinking methodology. The model found that the temporary living facilities are the alternatives that achieve the highest value. The result of this research effort was a value model that aids decision makers in identifying buildings for deconstruction.

15. SUBJECT TERMS

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